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Irrigated Soybean Production in Arid and Semi-Arid Regions

Proceedings of a Conference Held in Cairo, Egypt

31 August - 6 September 1979

Edited by W.H.Judy and J.A.Jackobs

International Soybean Program

INTSOY

Series Number 20

International Agriculture Publications, College of Agriculture, University of Illinois at Urbana-Champaign

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Sponsored by the Egyptian Ministry of Agriculture, Menoufeia University, and the International Soybean Program (INTSOY), in collaboration with the Food and Agriculture Organization of the United Nations (FAO) and the U.S. Agency for International Development

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CONFERENCE SUMMARY

Foreword

A Conference on Irrigated Soybean Production in Arid and Semi-Arid Regions was held in Cairo, Egypt, from August 31 to September 6, 1979. The conference was sponsored by the Egyptian Ministry of Agriculture, Menoufeia University, and the International Soybean Program (INTSOY). The Food and Agriculture Organization of the United Nations and the United States Agency for International Development collaborated and provided financial support. The objectives of the conference were to review the latest research results on the production of soybeans under furrow and flood irrigation, to identify problems, and to propose needed research.

This was the fifth conference cosponsored by INTSOY to bring soybean workers together to review the available soybean information and identify research and technology transfer needs. Three regional conferences were held in Puerto Rico, Ethiopia, and Thailand to review all aspects of soybean production, protection, marketing, and use. These general conferences and the experiences of growing and using soybeans under a wide range of environments showed the need for conferences focusing on particular problems. A workshop on Rust of Soybeans--the Problem and Research Needs was held in Manila, the Philippines, in early 1977. The proceedings of this workshop are published as Number 20 in the INTSOY Publications Series. The sponsors of the Conference on Irrigated Soybean Production in Arid and Semi-Arid Regions are pleased to add these proceedings to the INTSOY Series. The proceedings of a third specialized conference, Soybean Seed Quality and Stand Establishment, held in Colombo, Sri Lanka, will follow.

The expanding world population and rising income levels have resulted in an increased demand for protein and edible oils. Soybeans have proved to be an excellent food and feed source and the expansion of production, particularly under rain-fed conditions in temperate areas, has been rapid. The area in soybeans under flood and furrow irrigation has been increasing in arid and semi-arid regions throughout the world. Pressures to increase food production and the adaptation of soybeans to a wider range of environments are providing research data and farmer experience in growing the crop under irrigation. However, before the conference reported on in these proceedings, the research information was fragmentary and scattered and an assessment of research needs on an international scale had not been made. The conference sponsors and collaborators hope that the conference and proceedings will be a large step in meeting the need for a compilation of research results and the need for future information.

Productive international conferences require the efforts of many organizations and individuals. The sponsors wish to express their appreciation to all who combined their resources in such a cooperative and cordial manner to make this conference a success. The conference would not have been possible without financial and other support from the Food and Agriculture Organization of the United Nations and the United States Agency for International Development. A long list of organizations and individuals in Egypt supported the conference. The Organizing Committee was so important in setting the framework of the program and planning and conducting the conference that each member should be named and thanked: Mr. Saad Hagrass, Chairman, Ministry of Agriculture, Egypt; Dr. H.A. Al-Jibouri, Food and Agriculture Organization, Rome; Dr. Abdel Aziz, Agricultural Research Center, Ministry of Agriculture, Egypt; Dr. M.M. Dessouki, Ministry of Agriculture, Foreign Agricultural Relations Department, Egypt; Mr. Raafat Eskander, Secretary, Soybean Council of Egypt; Dr. William H. Judy, International Soybean Program (INTSOY); Dr. John Rogers, U.S. Agency for International Development, Cairo; and Dr. M.N. Shatla, Menoufeia University.

The Program Advisory Committee made many recommendations on program format, topics, and speakers. Mr. M.M. Dessouki ably chaired the Local Arrangements Committee and enlisted the assistance of many of his associates. Dr. M.N. Shatla chaired the Field Tour Committee and, with his colleagues, was a most gracious host when we visited Menoufeia University.

The conference participants who prepared papers and engaged in the discussions were the main contributors to these proceedings and deserve special thanks. Dr. William H. Judy, INTSOY, served as Conference Coordinator, chaired the Program Advisory Committee, and served on the Organizing Committee. He was involved in every aspect of the conference from suggesting the theme to the preparation for publication of these proceedings. Dr. Joseph A. Jackobs chaired the Abstracts and Manuscripts Committee, and served with Dr. Judy as co-editor of these proceedings. The conference sponsors express their special gratitude to Dr. Judy and Dr. Jackobs for their many contributions to the success of the conference.

INTSOY takes pride in sponsoring this conference with the Egyptian Ministry of Agriculture and Menoufeia University and in publishing and distributing these proceedings. We look forward to continued cooperation with national and international organizations in expanding the use of soybeans.

William N. Thompson
INTSOY Director

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Opening Address

M.M. DAWOOD
MINISTER OF AGRICULTURE, CAIRO

IT IS A GREAT PRIVILEGE TO WELCOME you to this conference and to have the pleasure of addressing you about our mutual interest in soybean production under irrigation.

The national agricultural policy of Egypt has been formulated to provide maximum food security within the limited agricultural land and the prevailing cropping rotation. Thus, one of the main goals of the policy is to create expanded soybean acreage in order to cover part of the deficit in edible oil production and to provide protein meal for our growing poultry industry.

The response of our farmers to the call to grow more soybeans in the last few years and their success in recording high levels of production per unit have been remarkable, and their accomplishments are unprecedented anywhere. The land in soybean production has jumped from about 1,700 hectares at an average of 0.8 ton per hectare in 1974 to around 34,500 hectares at an average of 2.3 tons per hectare in 1978. With a production total of 79,000 tons of soybean seed in 1978, Egypt has become self-sufficient in terms of the protein meal required for our poultry industry.

Although soybeans have been introduced as a commercial crop only recently, research on the crop has been going on for a long time. Efforts have been exerted to evaluate a big collection of introductions in different ecological zones of the country before releasing the current adapted varieties to farmers. The production of certified seed to cover the total annual acreage in soybeans was started in order to save the hard currency spent on importing seed every year. Parallel to this, studies have been conducted to establish the optimum agronomic practices for promising varieties to help realize their high yield potential in commercial production. A local nodule-producing bacteria inoculum which proved to be successful is being produced and tried on a large scale in farmers' fields. We hope to use locally produced inoculum to replace the yearly importation of inoculum. This would save the expense of using costly nitrogen fertilizers. Efficient pest-control measures are being recommended to farmers after thorough investigations.

Communicating information about soybeans to producers in the rural areas has been done through demonstration field plots, extension campaigns, radio and television, as well as agricultural journals and bulletins. Subsidized inputs of production such as seed, fertilizers, inoculum, and insecticides have been given to farmers on credit through cooperatives.

The achievements of our research scientists, extension officers, and all those who have planned and executed the policy of soybean introduction in Egyptian agriculture will not be forgotten. However, the challenge ahead is still great. Several channels could be used to further develop soybean production in Egypt.

1. The farmers on the old land in the Nile Valley and Delta should be encouraged to adopt appropriate production technology to fill the wide gap between the potential and the actual farm yields of the crop. For this, they will need to be given the means and the required imputs.

2. The new land prepared for agricultural production is our national breakthrough to a substantially greater acreage in oil crops. Investigations should be carried out to answer several questions relating to soil problems, water management, adapted varieties, as well as cultural practices, mechanization, labor availability, and marketing.

3. Work concerning the utilization and processing of soybean protein as human food should be undertaken to cover, even partially, the local needs for animal proteins which are costly and in short supply in relation to the growing demands of our people.

In general, the features and conditions of irrigated soybean production are considerably different from those in rain-fed areas.

Therein lies the importance and significance of this gathering, reviewing the present production situation and exploring the possibilities for further crop development. I trust that the exchange of information and ideas between the scientists assembled here will add much to our knowledge and will enhance the capabilities of researchers to tackle efficiently the problems of soybean production in our region.

We gratefully acknowledge the assistance and contributions of the University of Illinois and the staff of INTSOY to our national achievements in soybean production. Also, we hope their help will continue in the future. The endeavors of the staff members from FAO, UNDP, and USAID and all those who have organized and attended the meetings of this conference are highly appreciated.

Comments

S. HAGRASS

DEPUTY MINISTER OF AGRICULTURE, CAIRO

ON BEHALF OF THE SOYBEAN COUNCIL AND MYSELF, it is a pleasure to welcome the respected delegates and distinguished speakers to this conference on irrigated soybean production and to thank them for their participation. The subject of the conference is of vital importance to Egyptian agriculture, which has included soybeans only recently.

Until the early 1950's, cotton seed production has been sufficient to cover the major requirements for our edible oil and protein meal. At present, the annual production of processed cotton seed at 700,000 tons yields 100,000 tons of edible oil and 500,000 tons of protein meal. Both amounts represent only a fourth of our local requirements.

The deficit in both commodities is covered through imports. The supply of edible oils in the international market is unstable. The result could be a substantial decrease in the supply and a consequent rise in prices.

It would be difficult to cover our local needs in a time of crisis. In addition, the deficit in the production of cotton seed meal has had an adverse effect on the livestock and poultry industry in Egypt, resulting in reduced supplies and high prices for meat.

Thus, soybeans as a dual-purpose crop were introduced in the crop rotation. In 1972, the Egyptian Soybean Council was established, embracing all authorities concerned with production, marketing, processing, and research. The council was assigned the responsibility of drawing up the national policy for soybean development and enhancing studies and research programs that would increase production.

In this regard, the prices of fertilizers and costs of pest-control measures have been subsidized. Farmers have been able to market their crop at a high price, enabling them to get a satisfactory net return. The council has supported a project to produce certified seeds for use on 40,000 hectares annually, with the intention of ceasing seed importation by 1980. Research to develop, produce, and distribute *Rhizobium* inoculant has also been supported. Successful and consistent nodule production in farmers' fields from local inoculant will save the costs of importing inoculant and nitrogen fertilizers. Currently these costs are heavy, resulting in additional production costs. The extension service has also been strengthened to communicate to farmers recommendations about soybean production based on research results.

The soybean acreage in the 1979 season has already amounted to 40,000 hectares. Even so, soybean production is still far below our requirements for edible oil. On the other hand, the current needs of the animal feed industry will be almost satisfied at the present level of soybean production. In a few years, though, the projected expansion in soybean acreage will create a surplus of protein meal, particularly if the increase in animal feed consumption does not match the expansion in soybean acreage.

We should address ourselves from now on to the question of how to meet such situations in Egypt where animal-protein products are costly and undernourishment is a pressing problem. Utilizing soybeans in home recipes should be popularized, as whole seed, dehulled or processed separately, or in mixtures with other foods such as meat and flour. Large-scale, advanced technology in manufacturing low-cost protein products for human consumption should be sought and introduced without delay.

Through collaboration between concerned authorities at the national and international levels, efforts concerning the production and utilization of soybeans can yield fruitful results. I wish you all success in the vital deliberations at this conference.

Welcome to the Conference

W.N. THOMPSON

DIRECTOR, INTSOY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

ON BEHALF OF THE INTERNATIONAL SOYBEAN PROGRAM (INTSOY), it is my distinct pleasure to welcome you to the Conference on Irrigated Soybean Production in Arid and Semi-Arid Regions. INTSOY is privileged to be a joint sponsor of the conference along with the Ministry of Agriculture of the Arab Republic of Egypt and Menoufeia University.

The subject of the conference is an important one. Soybeans have become the dominant world crop in terms of producing vegetable oil and protein for animal and human use. Most soybeans are produced under rain-fed conditions. However, significant production of soybeans is also taking place under irrigated conditions, supported by associated research and development efforts. With the increasing demand for vegetable oil and protein, it seems clear that there will be a rising interest in producing soybeans under irrigation, usually in combination with other crops. Therefore, this conference was organized to review the latest research results on soybean production under furrow and flood irrigation and to identify problems and research needs.

At the outset of the conference, appreciation and thanks should be expressed to many organizations and individuals. The Food and Agriculture Organization of the United Nations (FAO) and United States Agency for International Development (USAID) provided financial support that made it possible for many participants to attend the conference and to defray other costs. Representatives from FAO and USAID also provided ideas and assistance to the Organizing Committee. Members of the Organizing Committee and Program Advisory Committee have been at work for many months and their work will continue through the conference and in publishing the proceedings. Appreciation should be extended to the American Soybean Association Regional Office in Madrid and to the Office of the Agricultural Attaché at the American Embassy in Cairo for the reception that provided the opportunity for conference participants to become better acquainted. I express the appreciation of the entire group, as well as my personal thanks, to Mr. Ed Quinones of the American Soybean Association and Dr. James Ross, the U.S. Agricultural Attaché to Egypt. With due recognition to the organizations and individuals just mentioned, the greatest expression of appreciation should be extended to the conference participants, most of whom prepared papers or country reports and are taking time from important responsibilities to participate in a conference that will benefit many organizations and individuals, including the producers and consumers of soybean products.

I want my welcome to be a warm one. In closing let me emphasize that this is a working conference. Its success will depend to a considerable extent on active participation during the conference sessions as well as in the informal discussions that occur during the breaks, at the hotel, and as we travel to and from Menoufeia University. I am confident that this conference will contribute to the INTSOY mission, which is to foster a network of cooperating organizations and individuals interested in exploiting the potential of the soybean as a source of food.

Statement on Behalf of FAO/UN

R. AL-GHOMIENY

DEPUTY REGIONAL REPRESENTATIVE, FAO/UN, CAIRO

IT IS A MATTER OF PRIDE FOR FAO TO COLLABORATE with the University of Menoufeia, the International Soybean Program (INTSOY), and the U.S. Agency for International Development (USAID) in the organization and presentation of this Conference on Irrigated Soybean Production. I am pleased to welcome you all on behalf of the Director-General. We are particularly grateful that the plan to hold such a conference has now been implemented successfully.

As a crop, soybeans are of special social and economic significance because they provide food, high-quality protein, vegetable oil, calories, feed, and raw material for agro-allied village industries. Soybean cultivation is steadily expanding, not only in the temperate regions but also to the subtropical and tropical regions.

This conference, though, is not like other meetings related to the improvement of already established crops. It is to deal

with a comparatively new crop of great future importance, and the prospects for soybean production under irrigated conditions are great. Technologies on irrigated soybean production have hardly been explored, and the potential in irrigated areas has not yet been fully exploited. Basic and applied research with respect to variety development through breeding, cultural practices, water use and management, soil fertility, soil salinity, crop protection, mechanization, cropping patterns, farming systems, processing, and utilization for food and feed have to be undertaken for the successful production of soybeans under irrigation.

I am delighted to see many scientists here from different continents. The papers to be presented and discussed during this meeting will help to identify the main constraints and developing strategies for increasing soybean production on both short- and long-term bases.

Please allow me this opportunity to acquaint you briefly with the soybean situation in the countries of the Near East Region in order to have your expert advice during the conference. This region suffers from an acute shortage of edible oils, necessitating large imports (including soybean oil) that cost millions of dollars every year. The countries in the region are very anxious to solve this problem. The successful introduction and commercial production of soybeans can partly help overcome the shortage of edible oil. As a result of efforts in this region, soybean cultivation has been taken up on a large scale in Iran, Egypt, and Pakistan. A good promise for this exists in other countries, such as Iraq, Syria, Afghanistan, and Maghreb.

The Food and Agriculture Organization of the United Nations has been assisting countries through the Regional Project on Field Food Crops by: (1) supplying varietal testing trials (in collaboration with INTSOY) and large quantities of seeds of identified varieties for extensive testing and early seed increase; (2) initiating cooperative agronomic studies on cultural practices (plant population density, rates and dates of seeding, and the like); (3) providing training for local scientists in the agronomy of soybean production at the University of Illinois; and (4) supporting the attendance of selected scientists at soybean meetings and seminars.

However, some constraints are holding back the large-scale production of soybeans. These relate to the availability of high-yielding varieties, arrangements for the production and storage of quality seeds, a lack of production know-how by farmers, as well as the lack of inputs, assured markets, and utilization facilities. Without the solution of these problems, soybean production will never take off, although it holds a bright future. I am confident that as distinguished scientists from soybean-growing countries, you will help us develop viable and practical programs to ensure success with soybean production in the Near East.

I anticipate that the conference will come up with practical recommendations for the initiation of research programs on soybean improvement and on production under irrigation on a cooperative basis involving national, regional, and international institutes and centers. The Food and Agriculture Organization will cooperate with and will help governments implement the recommendations to the extent that resources permit. The services of FAO's Seed Exchange Laboratory are available to interested researchers, and our training program for the development of research manpower at all levels is open to technicians. If desired, FAO might also help identify and formulate projects suited to international funding—apart from providing short-term consultants, holding meetings, seminars, and workshops, and providing technical information through our documentation and dissemination system which is open to all member governments and institutes.

I hope our joint efforts will result in the evolution of viable programs for the development and expanded production of soybeans, particularly for those countries where this crop has a great future. I am sure that all of the participants will take an active part in the deliberations and will make the meeting successful and productive. I wish you every success.

Conference Papers

Introduction, Promotion, and Production of Soybeans as an Irrigated Crop

P.F. KNOWLES

ABSTRACT: Many factors influence the successful introduction and establishment of a new crop such as soybeans, including the market, the biology of the plant, and development programs. The market factors that favor the establishment of soybeans include: a market for the oil, a good market for the meal, the availability of appropriate processing facilities, and a guaranteed market and price that will attract the interest of farmers. Favorable biological factors include: a broad-based research program covering all aspects of establishing the crop, the availability of suitable cultivars, the development and use of successful production practices and field demonstrations, the accurate identification of crop pests and the development of suitable control measures, and the genetic modification of the oil or meal, if necessary. These developmental factors would have a favorable effect on new-crop development: the availability of suitable land and of appropriate machinery for planting and harvesting; the provision of high-quality seed, a market, a suitable price, receiving and grading facilities, as well as storage, transportation, and agronomic services by the agency or company that is developing the crop; close cooperation between researchers, extension personnel, and administrators and the company or agency that is promoting the crop; and demonstrations on farms in the area showing the successful production of the crop.

THE LEADING CROP grown for oil and protein meal is soybeans. Since this has been true for several years, one might think that all the major production problems have been solved, and that soybean production should be possible easily within the economy of most countries with a temperate climate. Unfortunately, this is not the case.

Many countries and regions have tried hard to produce soybeans with limited results. Among these are India, Pakistan, the Middle East, North Africa, Australia, and California. Irrigation is used in many of these places.

In this paper, I will identify the factors that influence the successful commercial development of any oilseed crop having had experience both with the introduction of the safflower plant to California [Knowles, 1960] and with evaluations in California of sunflowers, rapeseed, and soybeans [Beard and Knowles, 1973]. As much as possible, I will focus my remarks on soybeans.

Three factors influence the introduction of soybeans to new areas, particularly areas that depend on irrigation. These factors are the market, the biology of the plant, and the developmental programs associated with introducing soybeans. Each factor will be discussed.

MARKET FACTORS

The market is not a problem in growing soybeans. In spite of the rapidly expanding area of production, both in the United States and Brazil, the market is not yet saturated. However, some features of the market can be examined.

The Need for Vegetable Oils

Many developing countries, including India, Pakistan, Iran, Iraq, and Egypt, have an increasing need for vegetable oils because of an expanding population, higher per capita consumption, and a decline in the availability of animal fats. Because of increasing prices for imported vegetable oils, all of the above countries have oilseed development programs. In such

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developmental programs the soybean may not have a high priority because of its low oil content.

A Market for the Meal

Most developed nations and some developing nations have a well-developed market for soybean meal, making the oil a byproduct. The high level of good-quality protein in the meal makes it useful in animal rations and human foods. Unfortunately, however, some developing nations do not have a well-developed market for soybean meal. This fact has restricted the commercial development of the crop.

Appropriate Processing Facilities

Because soybeans have a low oil content, solvent oil extraction is needed, alone or in combination with expeller extraction. Interest in soybeans was higher in California five years ago when cottonseed processing equipment was running at about 75 percent of full capacity. Now, with insufficient processing facilities to handle the seed from an expanded cotton crop, commercial interest in soybeans has declined.

A Guaranteed Market and Price

Commercial soybean production in California has usually involved a written contract between the farmer and a commercial company that guarantees both a market and a price at harvest. The same situation is likely in other areas where soybeans are a new crop. In some countries, an agency of the government will offer the contracts. There is often pressure on governmental agencies to offer minimum prices for oilseeds because of consumer resistance to the higher prices of vegetable oils. Where oilseed prices are low in relation to competing crops, the result is obvious: the oilseed crop is not grown.

BIOLOGICAL FACTORS

The soybean is a remarkable plant. A legume, it enjoys a good symbiotic relationship with a strain of the bacteria *Rhizobium*. Cultivars vary greatly in their responses to the photoperiod. Some cultivars have been reported to be day-length insensitive. The cultivars range from determinate to indeterminate. The following factors are of particular importance in soybean development.

A Broad-Based Research Program

When introducing any crop to a new area, research should identify or develop the ideal combination of genotype and environment. In California, in spite of a great deal of research on soybeans during the 1960's [Beard and Knowles, 1973], the crop did not become established. With the availability of better cultivars and the adoption of soybeans in double-cropping systems in the late 1970's, soybeans looked more promising [McClellan, 1979; Worker, 1979]. When introduced to an agriculture that depends on irrigation, soybeans will require research programs that blend the talents of researchers in several disciplines. Some aspects of such a program are outlined below and will be discussed in detail in other papers in the proceedings.

Availability of Suitable Cultivars

There is a great need for cultivars adapted to arid areas dependent on irrigation. The need exists at all latitudes where soybeans will grow. Most cultivars being tested in many countries of the world are products of American breeding programs. With the recent expansion of breeding programs by seed companies to include soybeans, very large numbers of new cultivars are likely to be available for testing. However, most of the cultivars available now and in the near future will be bred for the areas where soybeans are already being grown.

Production Practices

Production practices will be dealt with in detail in other papers. Here, it is sufficient to say that under irrigation there are usually several competing crops, many of them providing a higher gross income than soybeans. This situation requires efforts to fit soybeans into cropping systems where production costs will be reduced or where soybeans are sown with a companion crop, such as maize. A critical stage in soybean production is the harvest: first, because some cultivars may shatter; and, second, because the seeds are injured easily during threshing. Reduced germination, a consequence of improper threshing, has been a factor adversely affecting the commercial development of soybeans in India and Pakistan.

Pest Identification and Control

Mites (*Tetranychus* species) are major pests of soybeans in California [St. Andre, 1979]. These mites are usually abundant where relative humidities are low. The control of those pests, either through resistant cultivars or effective miticides, is essential for the large-scale production of soybeans in California. The mites are likely to be a problem in many areas with a Mediterranean climate, at least where mites affect other crops. The black thrip, *Caliothrips phaseoli*, is a serious pest in northwestern Mexico [Solario, Bernal, Salvidar, Martinez, Lopez, and Garcia, 1978]. Diseases have not yet been serious problems in arid climates of California.

Genetic Modification of the Oil and Meal

The commercial development of two crops, rapeseed and safflower, have been influenced favorably by the development of cultivars with a changed oil quality. In both cases, the cultivars with a changed oil quality serve as new oil crops. Soybean oil would be greatly improved for most purposes by the elimination of linolenic acid; and for some purposes, by increasing the amount of oleic acid, and reducing that of linoleic acid. Changes in fatty-acid composition of soybean oil over the next five years are not likely to have an impact on soybean oil use.

Reducing the hull thickness of the safflower seed raised its content of both oil and protein; also, the protein content of the meal was increased. Changes in the thickness of the seed coat of soybeans are not likely to appreciably change either the oil or the protein content. However, increases in the protein content will lead to reductions in the oil content.

DEVELOPMENTAL FACTORS

Often, new crop development fails not so much for the lack of a market or because the crop performs poorly, but because it has been difficult or impossible to put together an effective developmental program. As a consequence, some areas continue to be short of soybean oil, even though research results indicate that successful production is possible. Soybeans are not likely to develop as a crop in an area without a developmental program patterned after successful ones in other areas.

In the United States, developmental programs are often carried forward by one or more commercial companies, many times aided by public agencies. In Iran, the Oilseed Research and Development Company, which is supported by the government, has been the developmental agency [Anonymous, 1969]. Pakistan has under study a developmental program that will probably be run by a government corporation [Working Group, 1977].

These are some of the factors that lead to success. Each is important, individually and in combination with the others.

Land

Soybeans developed successfully in the U.S. Corn Belt partly because tractors replaced horses and mules, thus eliminating the need to devote millions of acres to the production of oats. In California, farmers are looking for summer crops to grow after wheat and barley, the ones grown in the winter. In Egypt, soybeans are grown as a companion crop with maize. For many areas with an irrigated agriculture, soybeans will not be strongly competitive in a single-crop system, but will fit well into a double-crop pattern.

Machinery

Where government agencies or companies contemplate the culture of soybeans, it should not be necessary to spend large amounts of money for equipment. Because soybeans will adapt to row spacings of 30 to 90 centimeters, a wide range of planting equipment can be used. Soybeans can also be drilled, a practice now growing in favor. Conventional combines can be adjusted to harvest the beans. Because the seeds are fragile, great care must be used in making machinery adjustments.

Services

When a new crop is introduced, established agencies usually cannot provide all of the necessary services. During the initial stages of crop development, most farmers will need assistance, advice, or both throughout the year. Often, too, established market channels will not handle a new crop.

The following services are needed:

1. Seed of an adapted variety and of good quality must be provided before planting. Seed procurement must begin well before planting time in order to arrange for transportation at the lowest cost. Where needed, seeds should be treated with an insecticide or fungicide by the sponsoring agency. In many instances, cost savings can be achieved if the seed is grown in the country where it will be used. However, this has often been difficult with soybeans. Germination has been low because of

excess moisture in the seed and high temperatures during storage. Sooner or later, an agency or company sponsoring new soybean acreage must develop its own facilities and an organization that will provide good-quality seed of the right variety.

3. Where specialized equipment is required, the agency or company should make it available, perhaps on a rental basis. If the new crop requires particular fertilizers, herbicides, or insecticides, the sponsoring agency or company should provide them. Where special applicators are needed, they must also be made available. With soybeans, inoculum will be needed and must be kept at temperatures that will retain the viability of the *Rhizobium*.
4. Advisory services must be provided by the sponsoring agency or company. Such services must be within easy reach of the farmer, or arrangements should be made to contact farmers frequently as they grow the new crop. Often, advisory service is required throughout the cropping season. As the farmers learn how to grow the new crop, the advisory services can be scaled down, but not eliminated. In most developing countries, the training and experience of extension personnel are not adequate to provide such service. Also, extension personnel are often too busy with regulatory duties to add advisory services for a new crop.
5. Storage facilities should be made available in the production area so the farmers can dispose of the crop easily and quickly. Similarly, transportation to processing facilities must be provided at the time it is required.
6. Facilities are needed for receiving the harvest and arrangements must be made for prompt payments to the farmers. When the seed is received, dockage should be determined and a grade assigned.
7. Close cooperation between researchers, extension personnel, and various administrators with the company or agency promoting the crop is essential. The cooperation should begin well before the new crop is sown. It may include: participating in demonstration plots; preparing publications; participating in extension-type meetings; and holding joint tours of new plantings. Close cooperation among researchers, extension personnel, and commercial companies contributed in an important way to the successful introduction of the safflower in California. The same cooperation prevails in the current testing programs for soybeans and rapeseed.

Demonstrations

Nothing is more convincing to a farmer than a demonstration on a farm with similar soil types and where familiar equipment is used. When safflower was first grown commercially in California, the average performance was very poor. A few farmers, however, achieved very high yields. Many of their neighbors were more convinced by the few successes than by the many failures. The neighbors learned the techniques of success and applied them in succeeding years.

CONCLUSIONS

The soybean has enjoyed great success in the United States, first in the Corn Belt and then in the southeastern states. It seems to be equally successful in Brazil. Northwestern Mexico has had marked success in growing soybeans under irrigation in a double-cropping system with wheat as the winter crop [Solario, Bernal, Salvidar, Martinez, Lopez, and Garcia, 1978]. In many other areas, particularly those with a Mediterranean climate, the same success has not occurred. As I see it, some of the reasons for such failures are:

1. The marketing component of development in terms of prices, receiving the harvest, and storage was not properly developed.
2. Research had not identified or developed successful cultivars, suitable production techniques, good pest-control practices, and satisfactory inoculation procedures.
3. Developmental programs left out key ingredients of success, such as providing high-quality seed, suitable equipment, and appropriate advisory services.

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Soybean Improvement and Production in the Near East and North Africa

A. HAFIZ

ABSTRACT: In view of shortage of edible oil, soybeans are gaining in importance in many countries of the Near East and North Africa. Since 1975, the Regional Project on Field Food Crops has been helping with variety trials and by providing large quantities of seeds and short-term training in agronomy production. Some constraints must be overcome in order to make soybeans a successful crop in the region. These constraints are discussed along with some suggestions.

THE MAIN SOURCE OF VEGETABLE OIL in most of the countries of the Near East and North Africa is cotton seed, but other oilseed crops are gaining in importance because of the big shortage of edible oils. One such crop is soybeans. During 1961-1965, the only sizable areas of soybeans were grown in Cyprus and Turkey. Soybeans were introduced in other countries during the early 1970's, notably Iran and Egypt; also, to some extent, in Pakistan, Iraq, Syria, and the Maghrab. In Iran, the area covered during 1977-78 was more than 70,000 hectares; in Egypt, 40,000 ha in the 1979 crop season. The average yields vary from 1 to 2.5 tons per hectare. Experiment yields have even exceeded 4 tons in some countries.

Starting in 1975, the Regional Project on Field Food Crops has been providing some help to interested countries in introducing soybeans and expanding the crop area. That help consisted of providing variety trials, large quantities of seed, and short-term production training.

VARIETY TESTING

Seeds of promising soybean varieties have been provided on a uniform basis through INTSOY[1] for yield performance. Later, seeds of different maturity types suited to each country were supplied. As a result, some countries identified these high-yielding varieties:

- Iran (Clark, Woodworth, Calland, Williams).
- Pakistan (Williams, Lee 68, Clark 63, Hampton 266A, Cobb, Bossier).
- Egypt (Calland, Clark, Williams).
- Syria (Cutler 71, Williams, Calland).

PROVIDING LARGE QUANTITIES OF SEED

Large quantities of seeds of identified soybean varieties were provided to Pakistan, Egypt, Syria, Afghanistan, Iraq, Iran, and the Sudan for extensive testing, seed multiplication, and release to farmers. This approach greatly helped extend the soybean area in some of the countries, which later also purchased large quantities of seeds on their own. Such help has been very useful in accelerating the diffusion not only of soybeans, but also of the established crops. The member countries very much like and support these efforts.

TRAINING LOCAL SCIENTISTS

Since soybeans are a new crop in most of the countries mentioned here, the local scientists are not aware of the large-scale production techniques for raising soybeans. In order to provide suitable training, the Regional Project has, so far, trained four persons at INTSOY in production agronomy for soybeans, one each from Egypt and Saudi Arabia and two from Pakistan.

[1]International Soybean Program, University of Illinois at Urbana-Champaign, USA.

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More persons with such training are needed. Also, the training programs need to be improved by: (1) introducing training for systems of farming built around the soybean crop; (2) adding the processing and use of soybean oil and soybean feed along with soybean consumption in food products (which will take a long time before becoming widely accepted); and (3) following up with the trainees during their post-training period. This would be possible because INTSOY is already supplying ISVEX[2] yield trials to many countries in the region. The Regional Project is also considering whether to subcontract the soybean work to INTSOY for an initial period of two years.

CONSTRAINTS

As a new crop, soybeans face many limitations in terms of being introduced and extended in the Near East Region. The first prerequisite is to find a place for the crop because it has to compete with the established ones—particularly cotton, maize, sorghum, sugarcane, and some summer food legumes as well as forage crops. In order to provide a strong base, soybeans must have a comparatively greater cash return, the appropriate incentive support from the government, or both. The technical constraints include the lack of: (1) high-yielding varieties suited to different crop zones in the region; (2) suitable programs for seed production and distribution; and (3) proper production knowledge as well as adequate marketing and utilization facilities. Since some of the technical barriers are being overcome through the preliminary identification of high-yielding varieties of soybeans and a keen interest by the governments in introducing and extending the cultivation of soybeans, some practical programs should be planned to achieve the goal.

SUGGESTIONS

1. Variety trials should be continued by supplying each country with only the seeds of the varieties that are likely to be suited to the prevailing soil and climatic conditions. To make the program more effective, it may be desirable to collect and collate all possible information on the agricultural conditions in each country in order to identify suitable areas for soybeans and to plan the type of work that needs to be carried out in each locality.
2. Since varietal development, agronomic studies, biochemical investigations, and the like cannot be undertaken in all interested countries, two or three well-equipped research stations should be developed in the region, ones set up to study the important groups of ecological conditions that will govern the intensive programs which then can also serve other countries in the region.
3. It is imperative to train a sufficient number of local scientists at all levels in soybean breeding, production agronomy, seed production, and utilization. In order to diffuse the information gained about improved methods, farm demonstrations and training for farmers will be needed. The countries should also be helped in preparing production-oriented programs covering all essential aspects of soybean production and marketing. The governments will also need to develop proper marketing, storage, and utilization facilities either in the public sector or the private sector.
4. Since soybeans will compete with maize, a system of inter-cropping should be developed to encourage farmers to take up the cultivation of the new crop.
5. Regular, technical backstopping should be provided in each country. The research workers, too, will need to have routine ways of gaining new scientific information through study tours, seminars and workshops, and various publications.

If well-planned steps are taken, there is a big future for soybeans—not only in helping meet the requirements for edible oil, but also in providing food products and feed that is rich in protein. In addition, soybeans will help build up the fertility of the soil through a diversification of agriculture and because of the special qualities of this legume plant.

[2]International Soybean Variety Evaluation Experiment.

Soybean Cultivar Development for High-Temperature, Semi-Arid Irrigation Culture

J.E. SPECHT AND C.D. NICKELL

ABSTRACT: Soybean breeding programs designed to develop cultivars suited to irrigation culture in semi-arid and arid regions with high temperatures are similar in most respects to those employed for temperate regions with humid and subhumid conditions. Plant introduction, pure-line selection, and mass selection can be employed to exploit the natural genetic variability available from indigenous or acquired cultivars in newly established production areas. Exploiting the genetic variability created by artificial hybridization can be accomplished by pedigree, bulk population, and single-seed descent methods. Backcross methods are useful in improving existing cultivars that are deficient in one or a few traits but are otherwise superior in performance. Long-term objectives can be attained with the use of recurrent selection in intermating populations. Intermating can be facilitated by genetic male sterility. S_1 progeny selection and selfed, half-sib family selection may be used to integrate selection schemes, although S_4 progeny selection may be used to integrate population improvement with cultivar development.

The choice of any breeding procedure is primarily a function of the availability and cost of the resources required and the amount of annual genetic gain desired. The latter is directly proportional to the genetic variability available and the degree of selection intensity, but is inversely proportional to the number of years required for each selection cycle and the size of the standard deviation of the total phenotypic variance.

Many breeding objectives are similar without regard to the environment for which the improved cultivar is desired. However, the unique environmental potentials and restrictions inherent in the high-temperature, irrigated culture of soybeans may necessitate an "ideotype" quite different from that for soybean culture in a temperate, rain-fed climate. The characterization of this ideotype is a crucial prerequisite for effective selection. A thorough understanding of the production environment and its interaction with the phenotype during all aspects of ontogeny is crucial. The phenotypic features of the soybean ideotype most likely to best exploit the potentials of a high-temperature, irrigation culture can be determined by both mechanistic and empirical approaches. Some probable characteristics of the ideotype include: greater heat resistance (or tolerance); minimal tendencies for floral and pod abortion; shorter, possibly determinate plants with greater resistance to lodging; and yield responsiveness to irrigations timed to coincide with the critical stages in ontogeny.

ONE OF THE MOST IMPORTANT FUNCTIONS of plant breeding is the development of high-yeilding cultivars adapted to a specific production environment—representing newly developing agricultural regions, new cultural practices and management systems, or both. The existence of interactions between genotypes and the environment, often substantial ones, support the idea of tailoring genotypes to fit specific environments. Selecting the genotypes possessing the ideal phenotype, or ideotype, that permits the best exploitation of the yield potential of a specific production environment is a major objective of most plant-breeding programs. To accomplish this objective, the breeder must determine, empirically or mechanistically, the characteristics and nature of the

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ideotype so that appropriate germplasm can be selected for manipulation by breeding procedures [Green *et al.*, 1972; Specht and Williams, 1978].

Inherent in this determination is a rigorous characterization of the production environment for which superior genotypes are desired. Such a characterization is necessary in order to optimize the use of components in the production environment, thus allowing the full expression of genetic potential and the greatest discrimination by the breeder among the many genotypes evaluated.

The expansion of soybean production from semiarid and arid regions, relatively intemperate ones, provides a case in point. In the arid regions with very low rainfall, irrigation becomes a critical component of the management system. Coupled with the higher temperatures characteristic of such areas, irrigation results in a unique production environment that differs substantially from that found in more temperate, rain-fed areas of soybean production. The type of irrigation employed (furrow, flood, sprinkler, trickle, etc.) as well as the magnitude, frequency, and timing according to the growth stage of the soybeans may also impose unique microenvironmental conditions for each system. These considerations are crucial ones and should be taken into account when developing breeding objectives.

The primary purpose of this presentation is to review breeding procedures for soybeans and objectives for developing cultivars to be used in a high-temperature, irrigation culture. A brief review of classical and current soybean-breeding methodology is given first.

SOYBEAN BREEDING METHODS

The breeding and selection procedures applied to soybeans are typical of those used for other self-fertilizing species with little or no outcrossing and for which additive genetic variance is the most important part of the total genetic variance. These procedures are described in most textbooks on plant breeding [e.g., Allard, 1960] and in the reviews and articles about soybean genetics and breeding already published [Brim and Cockerham, 1961; Johnson and Bernard, 1963; Hanson *et al.*, 1967; Bernard and Weiss, 1973; Brim, 1973; Brim and Stuber, 1973; Fehr and Ortiz, 1975; Brim, 1976; Singh, 1976; Cooper, 1976; Fehr, 1976; Kenworthy and Brim, 1979].

In addition, two conferences on world soybean research were held in 1975 and 1979. The published proceedings contain sections on soybean breeding. The references just given should be consulted for further details about the procedures covered here in brief.

Plant Introduction

Basically, this method involves importing soybean germplasm developed in nearby or distant regions into a new agricultural area. The acquired germplasm may be genetically variable, indigenous cultivars from agriculturally underdeveloped regions or high-yielding, genetically uniform cultivars from well-developed agricultural areas.

Pure-Line and Mass-Selection Methods

These are employed to select new cultivars from genetically variable introductions or indigenous cultivars [Allard, 1960]. Pure-line selection in its simplest form consists of: (1) selecting a large number of desirable plants from a diverse population; (2) visually observing the progenies during several generations and eliminating the obviously unsuitable types; (3) replicating field trials of the remaining selections over several years and in several locations in order to evaluate the performance of each one in relation to each other one and with established cultivars; and (4) selecting the single best progeny to use for increased development and to release as a new cultivar. Mass selection, although similar, differs from pure-line selection in that a number of lines, rather than just one, are composited to make up the new cultivar.

Selection After Hybridization

The objective of the planned hybridization of two parents is the recombination of the desirable genes present in each parent into a single genotype [Allard, 1960]. The identification and selection of this genotype during the selfing generations subsequent to hybridization (as homozygosity is rapidly approached) is the primary objective of the plant breeder. Various procedures (e.g., pedigree, bulk, single-seed descent, and backcrossing) are available to the soybean breeder when handling the segregation generations resulting from hybridizations [Brim, 1973].

The pedigree method probably is the breeding procedure most widely used with soybeans. It consists of selecting the most promising plants in the F_2 generation. In the F_3 and F_4 generations, single plants are selected again from the resultant progenies, but with the emphasis on selecting plants within superior families. In the F_5

and subsequent generations, when most families are homozygous at most loci, selection is practiced almost entirely among families. Detailed pedigree records are maintained. These are used to eliminate all but one of the closely related families with similar performance. Preliminary yield trials usually begin in the F_6 or F_7 generation.

The primary objective is to identify the few best families from each cross. The most promising strains are then selected for a comprehensive final evaluation and are replicated at several locations and times in order to critically assess agronomic performance in relation to proven cultivars. Strains judged superior in this final evaluation are then increased and released as new cultivars.

The bulk-population method involves the bulk generation advance of all the individuals in each generation, beginning with F_2 and continuing for several generations (usually from F_4 to F_7). At the termination of bulk propagation, individual plant selections are made and progenies are evaluated, the same as with the pedigree method.

Although various modifications of the pedigree and bulk procedures are used by soybean breeders, perhaps the most popular one is the single-seed, descent procedure, which has been outlined by Brim [1966, 1973]. The procedure consists of advancing each F_2 plant in a population to the F_3 and subsequent generations by harvesting a single seed from each plant in one generation for planting in the next generation. When the desired level of inbreeding is attained (usually in the F_4 or F_5 generation), individual plants are selected (each traceable to a different F_2 plant). Next, the progenies are evaluated in the same fashion as with the pedigree and bulk methods.

The backcross is a useful adjunct to the other methods in controlling the degree of segregation that occurs in a population after the initial hybridization of two parents [Allard, 1960]. Recurrent backcrossing may be employed to improve a cultivar that is deficient in one or more characteristics but is otherwise superior for most other characteristics.

Procedurally, the method consists of crossing the relatively superior cultivar with a relatively poor genotype that possesses a desired characteristic absent in the superior cultivar. The F_1 of this cross is then backcrossed to the recurrent superior parent. The subsequent backcross progeny is then backcrossed again to the recurrent parent. This process of backcrossing is repeated several times to recover the original characteristics of the recurrent parent, at the same time transferring the desired trait of the donor parent to the recurrent parent. Recurrent backcrossing is extremely useful in transferring qualitative characteristics governed by simple inherited genes (e.g., disease resistance and dwarfness) and has been used extensively in soybean-breeding programs with cultivars that are popular among producers.

Recurrent Selection and Population Improvement

The traditional breeding procedures just described are based on selection within populations derived by the hybridization of two homozygous parents. The fixation of desirable characters is accomplished by selection during subsequent selfing or backcrossing generations. Additional rounds of improvement are accomplished by hybridization and selection in new populations derived from two-way crosses of lines extracted from the previous round of selection. The limitations of this procedure are the: (1) amount of recombination that can occur, which is severely restricted by the rapid approach to homozygosity during the selfing generations; (2) limited magnitude of genetic variability possible within any given two-way cross; and (3) effectiveness of selection in increasing the frequency of desired genes and gene combinations before the random fixation of genes occurs during selfing [Brim, 1973].

Hanson *et al.* [1967] proposed recurrent selection by intermating populations to overcome these restrictions. Selection within populations derived from random matings of many parents, followed by intermating of the superior individuals and reselection, *ad infinitum*, theoretically should optimize genetic variability, maximize recombination, and gradually increase the frequency of desirable genes and gene combinations in the population because of the effects of cumulative selection. Others have also recognized these advantages [Compton, 1968; Brim, 1973; Fehr and Ortiz, 1975; Fehr, 1976; Kenworthy and Brim, 1979].

Perhaps the simplest scheme for recurrent selection in soybeans is as S_1 testing procedure involving three generations (intermating, selfing, and testing) in any one cycle of recurrent selection. A base population is synthesized by random hand-pollinations among many parents and random matings for several generations before initiating the first cycle of selection. Hybrid seed from the last intermating generation after population synthesis is harvested and planted to produce the S_0 plants grown in the selfing generation. Individual S_0 plants are harvested. The S_1 progeny are

evaluated in yield trials for agronomic performance in the testing generation. Superior S_1 progenies are identified and the remnant S_1 seeds of the S_0 parents of these selections are composited in equal amounts for planting the intermating generation of the second cycle or recurrent selection.

The primary limitations of using recurrent selection and population improvement in soybeans are the: (1) difficulty in obtaining the large number of crosses required for intermating schemes; and (2) lack of efficient means for agronomic testing of progenies consisting of small numbers of plants [Kenworthy and Brim, 1979]. Hill plot testing has been proposed for the latter [Fehr and Ortiz, 1975]; and the use genetic male sterility has been suggested for former [Brim and Stuber, 1973]. Genetic male sterility, while facilitating the process of intermating, results in the troublesome drawback of segregation for male-sterility in the testing generation, with subsequent increases in the errors associated with the variation in the number of male-sterile plants among yield plots. However, this effect can be minimized by adding more replications of the yield tests [Brim, 1966, 1973, and 1976].

Since the ultimate commercial product of soybean breeding is an inbred cultivar, S_4 testing has been proposed as a way of integrating population improvement producers (by recurrent selection) with standard cultivar development methods [Fehr and Ortiz, 1973]. In this procedure, the advance from the S_0 to the S_4 generation during the selfing phase is accomplished by single-seed descent. The testing phase then employs S_4 progenies. The advantage of S_4 testing is that selected, superior lines can be increased and released directly, whereas superior lines derived from S_1 testing must be selfed to a more advanced state of homozygosity and re-evaluated for yield potential before being released. Furthermore, inbreeding to the S_4 generation before testing results in a greater genetic gain per cycle [Brim and Cockerham, 1961].

ENVIRONMENTAL CONSIDERATIONS

Before a breeding program for soybeans can be successful in developing cultivars adapted to an irrigation culture in high-temperature regions with very low rainfall, the breeder must have in mind the phenotype most likely to elicit the best yield response in such an environment. A precise characterization of the appropriate ideotype may be difficult, however, without an intimate understanding of the key environmental components that interact with the phenotype and govern the response of that phenotype during various ontogenetic events, from germination to maturity. Critical considerations of these interactions between genotypes and the environment permits the breeder to make mechanistic determinations about the probable morphological and physiological features comprising the ideotype and supplements the subsequent empirical determinations necessary to confirm or deny tentative judgements concerning the nature of the ideotype. A review of the effects of temperature and irrigation on the response of soybeans is worthwhile with this context.

Temperature

High temperatures have a pervasive effect on all aspects of soybean growth and development, ranging from the molecular to the organismic. The temperature optimum for soybean germination (percentage and/or rate) and for hypocotyl elongation is near 30°C [Delouche, 1953; Hatfield and Egli, 1974]. As temperatures increase above 30°C, both the rate and percentage of germination decline and are eventually reduced to zero at temperatures close to and exceeding 40°C. The primary effects of higher temperatures are an increasing rate of denaturation and the inactivation of enzymes and the disruption of cellular membranes in the germinating seed [Milthorpe and Moorby, 1974]. Pathogenic attack by soil fungi may also occur, particularly when the soil moisture is high. Seed of poor quality or of especially large size is particularly susceptible to the deleterious effects of supra-optimal temperatures [Caviness, 1978].

Various studies have indicated to some extent the effect of high temperatures on vegetative and reproductive development. Runge and Odell [1960] observed that soybean yields were decreased when the daily maximum temperatures during July and August were 1°C higher than "normal." Thompson [1970] employed statistical techniques to evaluate the effect of temperature on soybean yields in five states of the North-Central United States from 1930 through 1968. A parabolic yield response was observed for departures from normal temperatures in July and August. The parabolic optimum (highest yield) did not coincide with the normal July and August temperatures, but was about a degree lower. Furthermore, the decline is yield was steeper with departures above (rather than below) normal. These two observations suggest that the soybean cultivars used in that region were not quite adapted and were not very yield-stable in terms of high-temperature response [Specht and Williams, 1978]. Higher temperatures in July and early August may lead to greater flower and pod abortion

[Van Schaik and Probst, 1958; Mann and Jaworski, 1970], and that may be critical in production environments with high temperatures. In addition, photorespiration and dark respiration increase at higher temperatures, thus reducing net photosynthesis and ultimately the amount of photosynthate available for storage in the seed [Thompson, 1970; Milthorpe and Moorby, 1974]. Higher temperatures also increase transpirational water loss [Shibles *et al.*, 1974].

Seed quality and composition are influenced greatly by the temperatures prevailing during seed development and maturation. Seed quality is important in terms of commercial market value as well as the seed retained for planting. Very hot conditions (above 33°C) during seed development substantially reduce seed quality [Green *et al.*, 1965; Cartter and Hartwig, 1963; Pendleton and Hartwig, 1973]. Delayed planting which advances seed maturation into cooler, fall temperatures is often practiced in some production areas to improve seed quality. High temperatures tend to increase the oil content of the seed [Howell and Cartter, 1963 and 1958] without significantly affecting the protein content, although high temperatures at night tend to increase the protein content [Shibles, 1974]. The linolenic and linoleic acid components of oil are inversely correlated with temperature [Howell and Collins, 1957]. Higher temperatures during ripening can also increase the respiratory losses in seed weight [Howell, 1963].

Irrigation

Substantial and prolonged moisture stress is an inherent characteristic of semiarid regions, necessitating irrigation as a key management component in the culture of most crops. Irrigation, however, can introduce unique stresses if it is inadequate or excessive, or if it is incorrectly timed in relation to specific critical stages in soybean ontogeny.

Soybeans are particularly sensitive to deficits of soil moisture during germination. Hunter and Erickson, [1952] observed that soybeans require a greater tension in soil moisture for germination than most other crops. Germination did not occur until the moisture content of the seed attained 50 percent of the dry weight. Saturated soil-moisture conditions are also detrimental [Grable and Danielson, 1965] slowing down root development and hypocotyl elongation and creating an environment favorable for pathogenic attack by soil fungi and bacteria. The initial seed quality governs the sensitivity of germination when the soil moisture is inadequate or excessive.

Runge and Odell [1960] were the first to demonstrate a differential yield response for soybeans supplied with supplemental water during various growth stages. Using statistical techniques to measure the yield response of soybeans to rainfall during a 50-year period in central Illinois, they observed that above-normal rainfall during mid-July (the late vegetative and flowering stages) and during mid-August to early September (the pod-filling stage) enhanced soybean yields, with the latter eliciting a greater yield response than the former. However, above-normal rainfall before early July (the vegetative stage) and during late July to early August (the pod-development stage) decreased soybean yields, with the former having the greater effect. The positive yield response to additional rainfall during the pod-filling stage was attributed to an enhancement of the dry weight of the seeds, presumably because of a lack of stress which might influence an efficient storage of photosynthate in the developing seed. Other investigators have also demonstrated the critical nature of these two stages in the yield response to supplemental water [Shaw and Laing, 1966; Dusek *et al.* 1971; Brady *et al.*, 1974; Sionit and Kramer, 1977; Ashley and Ethridge, 1978; Specht and Williams, unpublished data]. Doss *et al.* [1974] evaluated several irrigation schedules during a three-year period and observed that while irrigation at flowering enhanced yields, the effect was greater with irrigation at the pod-fill stage since the amount of water applied during pod-fill was highly correlated (r = 0.81) with the ultimate soybean yield. For each centimeter of water applied from August 15 to September 20, the yield was enchanced by about 125 kilograms per hectare. The lack of irrigation before flowering or during the pod-development stage had very little effect on yield. Doss and Thurlow [1975] demonstrated that daily water use by soybeans also peaked during flowering and again during pod-fill (the magnitude of the latter was greater than that of the former), thus coinciding with the bimodal yield response pattern observed by Runge and Odell [1960]. This pattern was quite characteristic regardless of the irrigation schedule used. However, moderate and very frequent irrigations did increase the overall amount of daily water use observed, suggesting a conditioning or acclimation of the soybeans to the water level available.

Irrigation has other characteristic effects on soybean growth, aside from yield. Doss and Thurlow [1974], Brady *et al.* [1974], and Ashley and Ethridge [1978] all observed that irrigation at any time before the

terminatin of vegetative growth significantly increased the height of the plant and its susceptibility to lodging. Since lodging tends to reduce yields, some attenuation of vegetative growth is necessary in order to reduce lodging. Indeed, supplemental water applied before the onset of flowering tends to result in excessive growth. Because of subsequent lodging, such growth may reduce yields [Runge and Odell, 1960; Brady *et al.*, 1974; Ashley and Ethridge, 1978]. Woods and Swearingen [1977] observed that lodging induced at any stage from early flowering to late pod-fill tended to reduce yields. Lodging during pod differentiation and development caused the severest yield reduction, primarily because of the substantial pod abortion. Interestingly, this stage corresponds to the "valley" between the two peaks of yield response to supplemental water [Runge and Odell, 1960] and between the two peaks of daily water use [Doss and Thurlow, 1974].

The growth characteristics of irrigated and nonirrigated soybeans have been evaluated in several reports [Stone *et al.*, 1976; Mayaki *et al.*, 1976a and 1976b]. The root system was similar in both cultures, except during mid-season when the dry matter in the roots was greater and the rooting depth was shallower under the irrigated culture. Seasonal water use was about 20 percent greater for the irrigated culture. The average vegetative growth rates, leaf area index, and total dry-matter accumulation were 1.5 to 2 times greater under the irrigated culture. Maturity is usually delayed, sometimes substantially, by using irrigation [Specht and Williams, 1978] probably because of the additional vegetative growth as well as the elimination of stress-accelerated senescence. The alleviation of water stress by irrigation tends to result in better seed quality [Pendleton and Hartwig, 1973] and may improve the protein and oil content of the seed. However, the yield enhancement arising from irrigation may also reduce the protein content because of the negative correlation between protein and yield [Brim, 1973].

The high temperatures and relatively low humidities of semiarid and arid environments generally restrict the development and severity of injury from most fungal, bacterial, and viral disease as well as the nematodes and insects that attack soybeans [Athow, 1973; Kennedy and Tachibana, 1973, Dunleavy, 1973; Good, 1973; Turnipseed, 1973]. However, an irrigated soybean culture may result in a canopy environment favorable to diseases, particularly if soil drainage is poor, irrigation is frequent, and the soybeans are grown continuously on the same land.

BREEDING OBJECTIVES

The breeding objectives anticipated in selecting soybean genotypes adapted to irrigated culture in high-temperature regions with semiarid and arid conditions are for the most part similar to those employed in more temperate, rain-fed regions. Brim [1973] and Hartwig [1973 and 1976] have outlined some of the general and specific objectives in soybean improvement. Obviously, the primary objective is yield improvement. Substantial genotypic differences exist in terms of yield responses to high temperatures, irrigation, or both [Mederski *et al.*, 1973; Mederski and Jeffers, 1973; Specht and Williams, 1978; Martineau *et al.*, 1979a and 1979b]. Minimum standards for the oil and protein content of soybean seeds are essential in most breeding programs, particularly when exotic germplasm is used in crosses or in intermated populations. Maturity plays a significant role in cultivar adaptation and must be considered in any breeding program. Resistance to dehiscence may be an important objective in environments where shattering before harvest is likely. Resistance to diseases, nematodes, and insects may be important where such injury could occur frequently. In highly productive environments, plant height is an important consideration because of its association with lodging and the effect height has on yields. In industrial processing of soybean seeds, certain seed pigmentation patterns are undesirable. So the breeder must keep these in mind during selection.

A high-temperature irrigation culture for soybean in semiarid and arid environments imposes some unique restrictions and potentials on genotype responses. Consequently, some breeding objectives may differ from those used for conventional environments, warranting further discussion.

Because seed quality is a crucial factor in obtaining stand establishment under supra-optimum soil temperatures when accompanied by either drought stress or excessive soil water, this characteristic should receive emphasis in the breeding program. Various laboratory tests are available for assessing genotypic performance concerning germination, emergence, and vigor under stress conditions [McDonald, 1976; Johnson, 1977]. Caviness [1978] used a field-screening technique to maximize environmental conditions favoring the deterioration of seed quality to permit optimum discrimination among genotypes in order to maintain seed quality despite unfavorable conditions.

The identification of heat-resistant genotypes is often difficult empirically because of an inability to achieve consistent

and reproducible conditions of heat stress in the field. Heat resistance in soybeans may be due to inherent tolerance mechanisms or avoidance mechanisms [Specht and Williams, 1978]. A mechanistic approach to screening soybeans for heat tolerance has been developed [Martineau *et al.*, 1978a and 1979b] and may be useful for soybean production in high-temperature regions. Screening for genotypes less disposed to floral abortion at high temperatures and to the shock of irrigations at flowering may be necessary as a selection criterion designed to improve seed set.

Any evaluation on the yield response of soybean genotypes to irrigation culture should include considerations of maturity, plant height, lodging, and diseases as well as the effects on yield components of the number of seeds per plant and the weight of the seed. Maturity adaption is crucial because of the tendency of irrigation to delay maturity [Specht and Williams, 1978]. Photoperiodism and maturity are also important in latitudes where two or more crops are grown per year [Hartwig, 1973].

Irrigation generally increases plant height, particularly if applied during the vegetative stages of growth, and thus increases the plant's susceptibility to lodging. Therefore, some attenuation of stem growth to minimize lodging is desirable. Shorter genotypes, perhaps with a determinant stem habit, provide a way of achieving this objective. However, a balance must be struck between shortening the plant height and maximizing the number of fruiting nodes, particularly at lower latitudes where photoperiodism governs the length of time between emergence and flowering. Irrigation culture may result in a greater frequency of soybean diseases, and disease resistance may become a major objective [Hartwig, 1976]. The timing of irrigation with respect to reproductive ontogeny will significantly influece the number of seeds per plant and seed weight [Specht and Williams, 1978]. Although these yield components generally are correlated negatively with each other, the degree of negative correlation and the response of each component to irrigation differ among genotypes.

SUMMARY

Soybean breeding programs designed to develop cultivars suited to irrigation culture in regions of high temperatures and very low rainfall are similar in most respects to the soybean-improvement programs employed in temperate, rain-fed areas. The breeding procedures employed are primarily determined by the soybean breeder—considering the resources available, the nature of the genetic variance, and the genetic gain desired per year. Plant introduction and pure-line or mass selection can be used to exploit the existing natural genetic variability. Pedigree, bulk population, and single-seed descent can be used to segregate materials derived from artifical crosses of selected parents. Backcrossing can be used to improve existing cultivars. Recurrent selection in intermated populations can be employed to maximize recombination, optimize the use of greater genetic variability, and improve the efficiency of selection. Many of the breeding objectives employed for soybeans raised in a temperate, rain-fed culture are also applicable to a high-temperature, semiarid, irrigated culture. However, the unique environmental conditions present in the latter environment may require a quite different ideotype in order to fully exploit the potentials of an irrigated culture. The characterization of the phenotypic features of this ideotype should be the main goal of the breeder.

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Producing Quality Seed for Arid Areas

E.E. HARTWIG

ABSTRACT: A primary factor in producing quality soybean seed for planting in any area is a well-adapted variety. At Stoneville, Mississippi (latitude 33° 20'), varieties maturing in October or early November produce seed of better quality than varieties that mature earlier. An adapted variety planted in mid-May or early June will produce better-quality seed than the same variety planted in April. Similar results have been obtained under irrigation at 26° to 28° latitude in western Mexico. Another factor in producing quality seed is to provide adequate moisture so the varieties will mature fully. Small seed types appear to produce better-quality seed under low moisture conditions than large ones. If the seed is harvested by machine, care must be taken in adjusting the combine to avoid damage to low-moisture seed. If the non-growing season is relatively warm and if the humidity is high, special storage conditions must be provided to maintain the seed at a moisture content of less than 13 percent.

THE AREA OF SOYBEAN PRODUCTION in the world under complete irrigation is relatively small. The principle region growing soybeans under complete irrigation is located in western Mexico between latitudes 26° and 28° where over 100,000 hectares are grown each year. The soybeans are planted in May or early June after a wheat crop is harvested. Wheat is planted after soybean harvest.

Many of the problems associated with producing quality soybean seed for planting under irrigation are similar to those encountered in other production areas. The number one requirement is to have an adapted variety. Varieties that mature during October produce seed of superior quality to those which mature earlier. Such varieties were developed for maturing under higher temperature conditions. However, temperatures during October are normally lower than in September.

In studies conducted at Stoneville, Mississippi, varieties of Maturity Groups VI or VII have produced seed quality superior to that from Maturity Groups IV or V. Considerable progress has been made in developing varieties of Group V maturity with improved seed quality. However, within the varieties of Group VI or VII, the seed quality from plantings made in mid-May or early June has been superior to that from the same variety planted in mid-April. The time of maturity would not have been changed.

The seed producer in an arid region would not be concerned with seed deterioration before harvest resulting from frequent rains. However, he must supply irrigation water of adequate quantity and over a sufficient time to permit the variety to mature completely. When the variety does not mature fully, seed may be reduced in size or become shriveled. In some cases, the cotyledons will remain green. Seed samples of the soybean variety Cajeme produced in the Obregon area of Mexico were sorted by hand to give a sample of well-developed seed with yellow cotyledons and another sample of immature, somewhat shriveled seed with green cotyledons. The germination of the latter lot was very poor.

Seed maturing under conditions of low humidity will drop to a moisture level of 8 to 10 percent very rapidly as the variety matures. When seed is machine-harvested, considerably more care must be taken to preserve the quality of the seed with a moisture content of 8 percent than of that with 13 percent moisture. Care must be taken to avoid splitting the seed and cracking the seed coat. Very dry seed may be damaged by impact even without showing evidence of external injury.

Observations have shown that large seed (18 g/100 seeds) is damaged more by handling under low-moisture conditions than is small

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seed (12 g/100 seeds). Studies at Stoneville have shown that when the Lee type (with an average weight per 100 seeds of 14 grams) is converted by backcrossing to a type having a 100-seed weight of 9 or 22 grams, the seed yield is not changed. These comparisions were made at an average yield of 3 tons of seed per hectare. Thus, a breeder developing varieties for arid regions need not feel that he will suffer a loss in yield potential if he attempts to develop small-seeded varieties.

After the seed is harvested, storing may become a problem, particularly if the temperature remains relatively warm and the air is relatively humid. In western Mexico, seed takes up moisture and deteriorates before the next planting season. For storage, seed should remain below 13 percent moisture. If the temperature is high for several weeks before planting, a moisture content of 12 percent would be advantageous. In Mexico, air-conditioned or dehumidified storage areas have become necessary.

The interaction between the moisture content of the seed and the temperature can be illustrated by storage studies conducted at Beltsville, Maryland. The germination of seed with a moisture content of 13.9 percent stored at different temperatures is shown below.

	Storage temperature (° C)			
Germination date	30	20	10	2
	percent germination			
March 13	98	99	97	97
May 3	87	99	96	97
June 6	40	97	91	96
July 10	0	98	95	94

The germination percentages for samples of the same seed lots stored at 9.4 percent moisture were:

	Storage temperature (° C)			
Germination date	30	20	10	2
	percent germination			
March 13	97	97	97	97
May 3	98	96	96	98
June 6	96	95	94	98
July 11	95	97	93	94

These results show that when soybeans are to be planted late in the season after another crop is harvested, great care must be taken to preserve the seed quality.

Soil-Fertility Requirements of Soybeans with Reference to Irrigation

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ABSTRACT: The purpose of this paper is to review recent literature on the mineral nutrition of soybeans under irrigation. Very little research has been conducted anywhere in the world on the simultaneous effects of irrigation and fertility. Recent advances in understanding the requirements of soil fertility are reviewed and the results of some new research combining foliar nutrient applications and moisture-level treatments are discussed.

THE PURPOSE OF THIS PAPER is to review the literature on the soil-fertility requirements of soybeans, especially in semiarid regions under irrigated conditions. Emphasis was placed on the findings of the last few years because at least 4 or 5 other reviews have been published on the subject since 1970 [Kurtz, 1976; Kamprath, 1974; deMooy *et al.* 1973; Scott and Aldrich, 1970; Nelson 1970]. Furthermore, annotated bibliographies have been prepared by the Commonwealth Agricultural Bureau at various times.

Reviews about the mineral nutrition of soybeans and their response to soil-fertility conditions were never easy to write because research on the topic was not coordinated very well and did not cover the entire field. Many field trials were not designed well enough for quantitative interpretation and did not make a contribution to our understanding of basic concepts about soybean mineral nutrition. A request for information on the nutritional requirements of soybeans under irrigation adds yet another complication. The quantity and control of the irrigation water must be adequately described in order for the experimental results on mineral nutrition to be interpreted properly.

Determining the optimum management conditions concerning water and fertility requires a simultaneous treatment of irrigation levels and fertility variables and the desired understanding of the difference between rain-fed and irrigated nutritional requirements and is derived from the interaction between the two factors. Such factorials dealing with both variables seem to be extremely rare.

The present topic is well chosen and is of great interest to those in regions with irrigation resources and problems in soybean management. A wide field of research activity lies unexplored.

LITERATURE REVIEW

Nutrient Accumulation and Transfer

NUTRIENT ACCUMULATION. The patterns of nutrient accumulation in various parts of the soybean plant and the subsequent translocation of nutrients into developing pods and seeds have been described by Hanway and Weber [1971a and 1971b]. The absorption, accumulation, and translocation at various rates of N, P, K application form the basis for an understanding of soybean nutrition.

Similar studies on nutrient and dry-matter accumulation have now been conducted in Brazil [Bataglia *et al.*, 1976], France [Chevalier, 1976], and India [Singh and Saxena, 1977]. The new studies provide similar data under different environmental conditions. Bataglia *et al.* [1976] reported the maximum accumulation of dry matter, Ca, Mg, and S after 90 days; K after 110 days; and P and N after 130 days. They determined the total amounts of nutrients accumulated by the plant and the percentages that were deposited in the grain.

Chevalier [1976] recorded in accumulation of dry matter and the nutrient absorption at various application rates for K, because K was in low supply in the soil. He found that the uptake of K and Ca was largely completed one month before that of N, P, and Mg. Application of K increased the uptake of K and also the N, P, and K content of the

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grain; but Mg uptake was suppressed. Chevalier presented the distribution of N, P, K, Ca, and Mg between the grain and the straw.

Singh and Saxena [1977] studied the dry-matter and P content of soybean plant parts at 15-day intervals as affected by various rates of N application. Like most previous researchers whose work has been reviewed earlier by deMooy *et al.* [1973], Singh and Saxena found decreasing P concentrations in the leaves and petiole with time and evidence of the translocation of P to the seeds. Applications of N stimulated P uptake and growth but reduced the P concentration in the plant tissue because of the dilution effect.

Researchers working under advanced management conditions are always aware that cultivars with higher production potentials will have greater nutrient requirements. In regions of the world where the technology is still being adapted to the local enviroment, however, the basic work with fertilizers, micronutrients, and their interaction with soil and water conditions is still in progress. The importance of soybean research lies in these interactions of fertility with water, cropping systems, tillage practices, varieties, disease and pest control, and climatic factors. Current research is not formulating a general theory to explain the differences in these interactions that have appeared in the literature produced around the world.

TRANSFER OF NUTRIENTS. Figueiredo [1975] studied the nutrient contents of soybeans in various row arrangements and described generally decreasing N, P, K, Ca, and Mg contents over time with a renewed increase of N and P after 80 days. Derman *et al.* [1978] showed that the transfer of N from the leaves to the seed started before the leaves began to turn yellow.

The transfer of nutrients from the leaves to the developing seed is closely related to leaf senescence and dihisence. The obvious interest in preventing leaf senescence during pod-fill is to continue the absorption of active nutrients and the process of N-fixation, as well as to promote the transfer of more nutrients to the seed—all of which would increase the productive capacity of the crop.

Hanway [1976] described how the natural processes of root growth, nutrient uptake, and N-fixation stop as the seed-filling progresses. N translocation takes over; the leaves become chlorotic and abscise.

Derman *et al.* [1978] showed that removing the pods prevented N redistribution and also caused other changes in mineral redistribution. The depletion of K, Mg, Ca, Mn, and Fe from the leaves was not responsible for yellowing because their content did not change during the process, whereas the content of N in the leaves decreased.

Mondal *et al.* [1978] removed the reproductive and vegetative sinks and, thereby, partially inhibited leaf photosynthesis in the top of the canopy. This inhibition remained constant from mid-bloom until maturity. There was also a gradual decline in photosynthesis, which was the same in normal as well as de-sinked plants. The de-sinked plants retained more dark-green leaves; but the green as well as the yellowing leaves showed the same decline in photosynthesis, which was not related to any of the characteristics measured by the authors such as the contents of inorganic phosphate, chlorophyll, protein, and carbohydrate in the leaves.

Nooden *et al.* [1978] found reduced leaf senescence in soybeans with pods only on the bottom half of the plant and leaves on the upper half. Continued pod removal further retarded leaf senescence. Pods located below the leaves could prevent senescence. Those above the leaves could not. Seed development and nutrient response could be separated. Seeds may affect senescence by means other than just a nutrient sink.

There are two ways of attempting to prevent leaf senescence. One is to provide mineral nutrients to the plants at an advanced stage of development. A foliar application is one of the methods involved, the results of which are reviewed later. The other approach is to incorporate the trait of delayed leaf senescence into otherwise desirable cultivars. Abu-Shakra *et al.* [1978] found such a soybean population, which also maintained high chlorophyll and ribulose-biphosphate carboxylase activity in the leaves and high N-fixation rates throughout maturation.

General Soil Fertility Factors

Soil management practices greatly affect the availability of soil nutrients. Incorporating straw, mulching, and tillage methods are some factors which have been identified. Straw incorporation may have several effects. Incorporated at the rate of 2 to 4 tons per hectare, straw increased N-fixation and soybean yields [Shivashankar and Vlassak, 1978]. The nitrogenase activity of root nodules was almost doubled at the 4-ton rate. Enrichment of soil CO_2 in combination with 4 tons of straw again nearly doubled the nitrogenase activity. Others also reported positive effects on soybean yields from CO_2 enrichment [Buriamaqui, 1976; Hardy and Havelka, 1973].

Therefore, incorporating the straw may provide a practical means of raising soybean yields based on the premise that photosynthetic limitations are an important cause of yield ceilings with soybeans. On the other

hand, a comparison by Veiga and Oliveira [1976] of incorporating 5 tons of wheat straw/ha at plowing time with other treatments (such as mulching with the same amount of straw 10 days after soybean emergence, direct seeding of soybeans in wheat stubble, and partial incorporation of straw) resulted in very little yield advantage (13 percent) for the best treatment, which was the partial incorporation of the straw. The reasons for the widely differing results need to be established.

Another effect of incorporating the straw or corn cobs reported in older literature is to immobilize the available inorganic nitrogen. In fact, this is a well-known technique for reducing available combined-N in the soil in N-fixation studies [Weber, 1966a and 1966b]. The principle involved is that of competition for available soil N between roots and microorganisms decomposing the straw.

Aluminum Toxicity and Liming

Two points need to be considered when seeking an optimum soil pH and liming policy for soybeans. First, soybeans—even those grown in the United States—seldom require a soil pH of more than 5.8 to 6.2 as noted earlier [deMooy *et al.*, 1973, p. 413]. Recent liming experiments in Alabama by Mitchell *et al.* [1977] confirmed the earlier findings. Yield responses from lime occurred at a soil pH of 5.2 or less, except where drought restricted the yield. Second, the problem of soil acidity and liming in highly weathered tropical soils centers around Al-toxicity.

The primary purpose of liming is to reduce the exchangeable Al to a harmless level. Work to this effect has been conducted by Mascarenhas *et al.* [1976]. They observed increased levels of P, K, Ca, and Mg in the soil as a result of liming. Martini *et al.* [1974] reported that liming to a pH above 5.4 was impractical. Generally, damaging amounts of aluminum have been removed from the soil at that pH. Other liming experiments have been reported from Puerto Rico by Pearson *et al.* [1977].

Reducing the Al saturation from 81 to 28 percent or 4 percent by liming resulted in an increased concentration of Ca in the plant and much-reduced concentrations of Al in most plant parts, except for the nodules, in greenhouse trials conducted by Sartain and Kamprath [1977].

In solution cultures by Wallace and Romney [1977], toxicity symptoms occurred when the Al content exceeded 30 mug/g in soybean leaves. The roots usually contained more Al than the leaves. High Al contents reduced the concentrations of Fe and Zn in the leaves.

Perez-Escobar [1977] found that exchangeable Al contents of 5.5 meq/100 g of soil reduced soybean yields by about half in the heavy textured soil of Puerto Rico. In coarse-textured soils, a soil pH of 4.8 to 6.3 and the percentage of exchangeable Al were not clearly related to yields because the total amounts involved were so small. But exchangeable Ca, Mg, and K were related to yields in all instances.

Soybeans are considered to be a relatively tolerant crop with reference to Al, especially if cationic nutrients are present in adequate amounts. Kang *et al.* [1977] pointed out that seed-pelleting with P, S, and Ca appears to be desirable in order to promote nodulation in acid soils until cultivars have been developed that nodulate and grow well in acid soils.

Nitrogen Nutrition

As a leguminous crop, soybeans are believed to have the capacity to fill most N requirements through the fixation of atmospheric N_2 in symbiosis with rhizobia. Soybeans absorb combined N from the soil if available, but do so at the expense of utilizing symbiotic-N resources. This is the basis of the well-established linear inverse relationship: the application of inorganic N fertilizers results in reduced symbiotic N-fixation by way of substitution which takes place without loss in yield. The concept has been discussed by various authors since the 1940's, one of whom is Weber [1966b]. Many investigators have agreed with the principle of an inverse relationship stating that the application of N fertilizer to well-nodulated soybeans is unnecessary, or at least unprofitable. Some of these studies published in recent years are by Chesney [1973], who worked in the humid tropics; Chesney *et al.* [1970]; Criswell *et al.* [1976]; Karyagin and Tolstenko [1973]; Lorenz [1974]; Reis *et al.* [1977]; Singh and Saxena [1972]; and Welch *et al.* [1973].

In non-nodulated beans, Pal and Saxena [1977] found that leaf areas were reduced by N applications exceeding 200 kg/ha in India. Trang [1977] reported more growth reduction from N applications under shade than when not shaded.

Despite the general rule of negligible advantages from the effects of N application, reports of considerable responses from applied N continue to appear. Aleman and Franco [1976] conducted factorial trials for optimum N and P fertilization and arrived at quite high N requirements (600 kg/ha) for a maximum yield. Kang in Luse *et al.*, [1975] reported greatly increased yields from N fertilizer applications of up to 120 kg/ha of N after inoculation in the humid tropics.

There are those who claim that small additions of N fertilizer further increase the yield of well-inoculated soybeans. They include Nangju [1975] at IITA, Kang [1975] in western Nigeria, Herath [1975] in Sri Lanka, and Longeri and Herrera [1972] in Chile.

The recent studies include those by Bhangoo and Albritten [1972], who reported increases of 10 to 15 percent in seed yield from N applications of 112 kg/ha except in dry years, Rioz and dos Santos [1973], and Haque [1977]. Haque reported maximum yields with the highest rate of N applied (90 kg/ha), even with inoculated soybeans, but not every year. Such a sporadic yield response was also reported by Bishop *et al.* [1978]. Statistically significant responses from N applications were found in 1972 but not in 1973; whereas responses occurred at one site but not at another in 1974.

The controversy may be caused by several factors, especially since an increasing number of investigations are being made in tropical regions. The experiment by Haque was conducted at the end of the wet season in Sierra Leone. Pettiet [1971] found in Mississippi that soybeans responded to N under dry conditions but not under irrigation. Nitrogen mineralization may be greater as rainfall increases. Less than full efficient nodule activity may be another factor in some instances, despite careful procedures with seed inoculation.

Most discrepancies might be brought into general agreement if the total amount of available soil N present in the entire root zone at any time during the growing season were taken into account. Few researchers, however, are prepared to undertake the laborious task of intensive sampling and a chemical analysis of the soil to the full depth of rooting at regular intervals during the growing season.

Few would claim that soybeans can fill all N requirements from symbiotic N-fixation. When nitrogen is plentiful in the field, Harper [1974] estimated a range of 25 to 50 percent, making the contribution from symbiosis secondary to uptake from sources of nitrogen in the soil.

Decau *et al.* [1976] determined the contribution of bacterial N to the total N content on the basis of the nitrate content of the plant. They set out to determine whether a compensating effect of the N-fixation metabolism on the absorption of mineral N by the roots exists or whether the two N-absorption mechanisms are independent. They grew nodulated and non-nodulated soybeans in the field under irrigation at four rates of NO_3 application and sampled plant tops periodically for total N and NO_3 content. Their results indicate that: (1) the two N-absorption mechanisms are not independent; and (2) the field method gives a good approximation of the total amounts of N contributed by root uptake and N-fixation.

EARLY GROWTH STAGES. The period between emergence and the beginning of effective nodule activity is a logical one for a response from applications of nitrogen. However, a visual response at this stage does not guarantee a yield increase because soybeans often recover from nutrient deficiences incurred during early stages of development without a loss in yield. Beard and Hoover [1971] reported a yellow discoloration of the leaves until the plants were 30 cm tall at 30 to 40 days after emergence, indicating a nitrogen deficiency; but a preplant application of 56 kg/ha of N as a ammonium sulfate caused a sharp reduction in the number of nodules per plant. A lower rate of N application might have corrected the N deficiency and, thus, prevented a decrease in nodulation. However, such rates were not used in that study. Williamson and Diatloff [1975] found no ill effects on nodule numbers when up to 34 kg/ha of N was applied in Australia.

Hatfield *et al.* [1974] reported that nodulation was stimulated by adding small amounts of N during 2 weeks after emergence in the greenhouse. The dry-matter yields of inoculated plants were not maximized with less than 4 weeks of supplemental nitrogen. Uninoculated plants attained the same dry weight as inoculated ones after 6 weeks with an additional N supply. Tran and Hinson [1977] applied N at rates of 30 and 60 kg/ha in bands 30 cm wide over the rows. After 38 days, the nodule numbers were reduced by one-third and nodule fresh weight by one-fourth; but the N-fixation per unit of fresh weight was increased by one-third. The next year, the residual effects created by adding 60 kg/ha of N were noticeable 85 days after planting. Significantly less N was fixed by those plants than by the control plants.

The period of N shortage in the seedling stage may be relatively more important in tropical lowland conditions than in temperate regions because of the extremely low availability of soil N at critical times, a faster rate of N uptake in the tropics, and perhaps an earlier flowering of soybeans under conditions of restricted daylight, as suggested by Leng [1973].

NODULATION. The effect of N fertilization on nodulation has received much attention because it concerns a rather fundamental aspect of N nutrition in soybeans. The presence of nitrates generally affects the

initiation of nodule development and functioning alike. Yet, urea had no inhibiting effect at 6 times the concentration at which nitrates caused an inhibition of nodule development [Harper, 1976]. Urea is absorbed more slowly than nitrate, perhaps explaining the difference. The urea could have provided fertilizer N to soybeans in an already reduced form, which would not affect nodule activity.

BLOOM. High rates of flower and pod abortion in soybeans may be partially due to a lack of adequate nitrogen. Brevedan *et al.* [1978] managed to reduce flower abortion from 55 to 45 percent by the application of combined nitrogen. The yield increases obtained in the field and greenhouse were 28 and 33 percent, respectively. Nitrogen was broadcast on the field at the rate of 168 kg/ha at the beginning or end of bloom, or both, and was washed into the ground by sprinkler irrigation. The increased seed yield resulted from more seeds per plant and, sometimes, partly from an increase in the size of the seed. Other reports such as the one by Beard and Hoover [1971] showed no effect on nodulation or yields from N rates of up to 112 kg/ha applied at flowering.

RESIDUAL NITROGEN. Another suggestion about the absorption of organic N is implied in the notion that soybeans respond better to residual nitrogen than to a direct application of N fertilizer. The response to nitrogen that has been in the soil for a year or more includes that possibility that a transformation into organic nitrogen has occurred and that it has been absorbed by the roots [Bezdicek *et al.*, 1974].

PHYSIOLOGICAL DIFFERENCES. Applied N may replace symbiotic N in soybeans, but the physiological processes involved may differ so that plant dry-matter for a given seed yield from inoculated plants could be lower than that from uninoculated plants treated with combined N [Coic, 1975]. This and other differences between nodulated and non-nodulated plants were discussed in an earlier review [deMooy *et al.*, 1973]. Ryle *et al.* [1978] pointed out that plants supplied with an abundance of nitrate-N assimilated 3 to 4 times as much N as nodulated plants wholly dependent on N-fixation. Moreover, 40 percent of the N from nitrate-N was assimilated after the nodulated plants had stopped fixing nitrogen. Respiration in the roots of plants dependent on N-fixation was twice as fast as in those dependent on nitrate-N, which made a difference of 10 to 15 percent in whole-plant respiratory loss. Therefore, plants that were dependent on N-fixation grew slower than those supplied with nitrates because of the lower amount of assimilated-N and the relatively high energy demands of symbiosis compared to the NO_3 reduction in the leaves.

Phosphorus Nutrition

The phosphorus requirements of soybeans grown under temperate climatic conditions and the effects of P nutrition on nodulation and N-fixation have been thoroughly evaluated over the last 50 years and have been reviewed previously [deMooy *et al.*, 1973]. In the developing countries, the range of environmental conditions and soil varieties is wider than elsewhere, for which optimum P application rates and fertilizer policies still need to be defined.

Shukla [1970] reported on P responses for the clay soils of Guyana. Later, Chesney [1973] showed further evidence of large, linear responses from moderate rates of P fertilization on clay loam soils having low available P in the same country.

Lasserre [1977] reported an increase of 4.74 kg of seed per kg of applied P_2O_5 and recommended rates of up to 120 kg/ha of P_2O_5 for Argentina. Haque [1977] observed increased nodulation and an increase of 113 percent in grain yields with rates of up to 60 kg/ha in Sierra Lone. However, at 90 kg/ha of P_2O_5, yield reductions occurred that were ascribed to induced Zn deficiency. In phosphorus studies in Louisiana, similar rates of 99 kg/ha resulted in maximum yields, although plant height and lodging were increased [Lawrence *et al.*, 1976].

In Nigeria, soybeans responded to residual fertilizer P remaining after 2 to 5 maize crops. Original applications up to 104 kg/ha of P resulted in large increases in yields and in the percentage of seed protein during later years.

Interactions with other elements such as N, Zn, and various micronutrients are closely allied to phosphorus nutrition. Uriyo [1974] reported an interaction between P and Mo in the soils of Tanzania. Soybean yield responses from P applications occurred; but at high rates of P application, the addition of Mo decreased seed yields.

The lack of response from P applications in spite of low P soil tests may be caused by a number of factors, one of which is drought. Mitchell *et al.* [1977] reported on the lack of P responses in Alabama.

Mycorrhiza have a profound effect on P nutrition. The association of soybean roots with mycorrhiza was recognized in 1970 by Ross and Harper. Ross and Gilliam [1973] showed that mycorrhizal plants were capable of removing more P from the same sources

that were also available to non-mycorrhizal plants. Schenk and Hinson [1973] added that significant increases in seed yields occurred only when the soybeans inoculated with *Endogone macrocarpa* were also nodulated. Mojallali and Weed [1978] observed increased P uptake from soils of low fertility in the presence of mycorrhiza, but plants that were not inoculated with mycorrhiza were P-deficient. However, K-deficiency symptoms developed in plants where mycorrhiza had prevented a P-deficiency. An enlarged uptake of P is usually observed. The suggested mechanism is the dissolution of soil P by the acidifying effect of the micorrhiza.

Foliar applications of P in combination with other nutrients are the object of current study. New compounds suitable for foliar applications of P were identified by Barel [1976]. Ammonium tripolyphosphate increased soybean yields significantly in a field trial. Soybean leaves can tolerate only two-thirds to three-fourths of the quantity applied to maize leaves (370 mug P/cm^2).

Garcia and Hanway [1976] and Garcia [1977] used a P polyphosphate source in combination with quantities of N, K, and S in which the ratio of N, P, K, and S was 10:1:3:5, respectively, which reflects the composition of the seeds. Foliar applications were made 3 to 4 times during the seed-filling period to prevent a depletion of those nutrients in the leaves from the translocation process and reduced uptake from the soil.

Significant yield responses were reported —depending on the cultivars, time of application during the growing, number of sprayings, and rate of application per spraying. Rates of application can also be too high. Garcia and Hanway found that 80, 8, 24, and 4 kg/ha of N, P, K, S, respectively, led to the best results under the conditions associated with their yield responses were caused by greater numbers of harvestable seeds.

McClure *et al*, [1976] discovered that ferulic acid at a concentration of 0.5 mM/1 inhibited P uptake by soybean roots, but not the translocation of already absorbed phosphate in the plant.

Potassium Nutrition

Potassium responses are governed by many factors. In developing regions such as Guyana and Brazil, new soils are being evaluated for K fertility [Shukla, 1970; Mascarenhas *et al*., 1970]. Bhangoo and Albritton [1976] showed that K responses of 9 to 19 percent obtained from K applications in Arkansas did not occur in dry years. The red tropical soils present new challenges. One study by Mascarenhas *et al*. [1976] described how liming such a soil raised the level of available K and other nutrients enough to render any rate of K fertilizer application ineffective in increasing soybean yields.

An almost limitless range of K requirements and responses can be anticipated from a variety of soils in combination with climatic conditions. The degree of leaching taking place over a long time depends not only on the rainfall regime and temperature, but also on soil texture. Soil texture can reverse climate effects because certain clay soils can retain K against the leaching power of the humid tropics. At the other extreme are sandy soils that would be devoid of K fertility even in subhumid areas. Chesney [1973] reported on the response to K applications on a clay loam in the humid tropics. An increased seed yield occurred during a particularly wet season, and the K effects were larger with higher rates of N application. Nelson [1977] published examples of economic returns from K applications in several areas of the United States and Canada.

Potassium has an important side function besides direct nutrition in disease control. Mascarenhas, Hirase, and Braga [1976] related K responses in soybeans to the available K content of the soil. They established a threshold value below which fertilizer application is desirable for two purposes: nutrition and the control of a fungus disease [*Diaporthe phascolorum* (Cke et Ell.) *Sacc*. var. sojae (Lehman)Wehm]; also, a maximum soil value above which further application has undesirable effects on the plant. Camper and Lutz [1977] described a combination of yield responses from K applications on sandy loam soil and the favorable effect of K on stem blight (*Disporthe phaseolum*), purple seed stain (*Cercospora kikuchii*), and seed shattering.

Other Nutrients

Despite their important nature, these nutrients have not been the subject of much direct research since previous reviews. Zinc, Fe, and Mn interact strongly in the absorption process. As is well known, Fe uptake is reduced in the presence of high concentrations of zinc. Most of the literature on this subject has been reviewed earlier [Lingle, Tiffin, and Brown, 1963], but some thesis work has been reported from India [Napoor, 1972].

Conversely, Zn uptake is reduced by high Fe concentrations. Reddy, Saxena, and Pal [1976] found in short-duration uptake studies that Fe concentrations of 5 ppm or more strongly reduced Zn uptake from concentrations of 0.005 to 5.0 ppm of zinc. Iron concentrations of 1 ppm or less had little effect. Manganese also showed an interference with Zn uptake, but in a different manner. A

linear decrease in Zn uptake from 0.5 to 5 ppm occurred over a range of 0.05 to 5.0 ppm in Mn concentrations. Most of the reduction in Zn uptake from Zn solutions of 0.05 ppm occurred at the lower Mn concentrations. At a still-lower Zn concentration (0.005 ppm), the opposite effect occurred. The uptake of Zn was improved in the presence of Mn, especially at higher concentrations. From nutrient solution work, DeMeterio *et al.* [1972] reported that a deficiency of Zn resulted in reduced nodulation and N-fixation.

Interaction of Irrigation and Fertility

Since soybeans require relatively good moisture conditions, one would expect to find much research activity with irrigation in relation to fertility levels. The opposite appears to be true.

Another handicap is often encountered in the term "widely applicable." Irrigation levels may be defined on the basis of fixed intervals of time, quantities of water applied, or "Class A" evaporation pan data—which undoubtedly have significance under regional climatic and soil conditions, but have little relevance to broader applications.

To be widely applicable, such results would have to be expressed in terms of moisture stress levels at a certain stage of plant development, e.g., in bars of tension because such units are independent of soil type and texture. Yet, this is seldom done. Similarly, fertility experiments frequently lack information about the environmental factors or inherent levels of soil fertility according to internationally acceptable standards concerning the availability of soil nutrients. Such experiments have little to contribute to an international evaluation of techniques relating to nutritional and fertilizer applications.

Lutz and Hale [1973] combined irrigation, lime, P, and K fertilizer rates and plowsole placement in India. Seed and hay yield responses from irrigation occurred, but the degree of moisture stress on unirrigated plots was not determined. The number, weight, and size of the seeds were all increased greatly. The oil content of the seed was also significantly increased by irrigation (approximately 0.5 percent). Fertilizer treatments had no significant effect on yields, and there was no evidence that the nutrient requirements changed under irrigation treatments. Irrigation did not affect the concentration of P and K in the leaves.

When residual effects are considered, another complication enters the field of irrigation and fertility investigations. All treatments must be repeated for a second season. Also, the effects of irrigation or fertility during seasons may not be comparable. Therefore, it is desirable to reserve spaces in the field design for identical treatments that will be applied during the second season. In this way, the residual effects can be expressed as a fraction of the original direct effect, had it been applied during the second season.

Ladd and Lakbhor [1976] studied the residual effects of irrigation and of N and P applications on soybean yields. They found that the available P content of the soil before soybean planting was raised by the quality of the irrigation water, the rate of P applied, and the interaction of I x N x P during the previous season. The subsequent soybean yields were increased by the same irrigation treatment that had raised the available P level of the soil. The experiment did not allow for the separation of the residual effects of irrigation and phosphorus. It would have been necessary to include a newly irrigated plot during the yield test to resolve this problem of confounding irrigation and P effects.

CURRENT RESEARCH

Effects of Foliar Fertilization and Irrigation Timing on the Yield Response of Soybeans

The foliar fertilization of soybeans is a new practice, particularly in the Midwestern states. The Allied Chemical Corporation has manufactured a foliar fertilizer solution, Folian, which became available commercially for the first time in 1977.

Results from research performed at Iowa State University during 1974 and 1975 [Garcia and Hanway, 1976] indicated that soybean yields could be increased by as much as 1,570 kg/ha by using a foliar fertilizer spray. Yields were the highest when soybeans were sprayed with the solution 2 to 4 times at 7- to 10-day intervals during bean development (the pod-fill stage). The fertilizer solution contains N, P, K, and S in specific proportions. The optimum total application rate was determined to be approximately 80, 8, 24, and 4 kg/ha for N, P, K, and S, respectively. The yield increases appeared to be due to increases in the number of harvestable beans.

One objective of the field study at Fort Collins during 1976 and 1977 was to be determine whether foliar fertilization increased the yield of soybeans grown under irrigation and to evaluate the response under different timings and levels of application of irrigation water.

EXPERIMENTAL DESIGN AND TREATMENTS. The soybean variety Hodgson (short-season, group I

maturity) was inoculated just before seeding and was planted in rows 56 cm apart on June 7, 1976. The plant population was 205,000 per hectare.

Prior to planting, the plot area was irrigated by sprinklers with approximately 30 cm of water to bring the top 259 cm of the soil profile to field capacity. After 1 cultivation, neutron probe access tubes were installed and the field was divided into 4 plots. The plots consisted of 60 rows of soybeans, each row being 15.3 m long. Each plot was divided into 2 subplots. One subplot was foliar fertilized and the other was not fertilized. The only other fertilizer applied was 92.1 kg/ha of P distributed evenly over the entire field before planting.

A single sprinkler line extended through the center of the field parallel to the rows. The experimental design provided for a uniform water application parallel to the sprinkler line, with decreasing applications as the distance from the line increased. Thus, the outside rows (treatment A) would receive little or no water during an irrigation, while the rows close to the sprinkler line would receive high levels of water (treatment E). The plots were separated by borders 30.5 m wide and borders half that wide at the two ends of the field. Four irrigation treatments were incorporated. This allowed for periods of water stress during critical stages of growth.

The soybeans that were to be fertilized by the foliar method in 1976 were sprayed 4 times at intervals of 7 to 10 days after bean development had started with N, P, K, and S in the fertilizer solution. The total nutrient application was approximately 80, 8, 24, and 4 kg/ha of N, P, K, and S, respectively. The sources of the nutrients were:

N-Urea
P-Potassium polyphosphate
K-Potassium polyphosphate and potassium sulfate
S-Potassium sulfate

In 1977, the soybeans were sprayed 3 times at 7-day intervals. The total nutrient application was 60, 6, 18, and 3 kg/ha of N, P, K, and S, respectively, applied as Folian. The plant population in 1977 was 223,500 kilograms per hectare.

The soybeans were harvested for seed and samples were sent to the National Soybean Laboratory at Urbana, Illinois for an analysis of the protein and oil content.

SOIL MOISTURE MEASURING AND DETERMINING EVAPOTRANSPIRATION. The moisture content of the soil was evaluated by using the neutron scatter technique. From the time the access tubes were installed, neutron probe readings were taken at depth intervals of 30.5 cm just before each weekly irrigation. Neutron

Table 1. Summary of Irrigation and Fertilizer Treatments, Soybean Field Study, Ft. Collins, Colorado, 1976 and 1977

Treatment designation	Fertilizer treatment	Stage of growth: Flower	Stage of growth: Pod development	Stage of growth: Bean development
1976				
0III	....	Irrigation	Irrigation	Irrigation
0III-F	Foliar application	Irrigation	Irrigation	Irrigation
0I0I	....	Irrigation	....	Irrigation
0I0I-F	Foliar application	Irrigation	....	Irrigation
000I	....	....	....	Irrigation
000I-F	Foliar application	....	....	Irrigation
00I0	....	....	Irrigation	....
00I0-F	Foliar application	....	Irrigation	....
1977				
0I00	....	Irrigation	....	....
0I00-F	Foliar application	Irrigation	....	....
0III	....	Irrigation	Irrigation	Irrigation
0III-F	Foliar application	Irrigation	Irrigation	Irrigation
00I0	....	....	Irrigation	....
00I0-F	Foliar application	....	Irrigation	....
00II	....	....	Irrigation	Irrigation
00II-F	Foliar application	....	Irrigation	Irrigation

readings were taken to a depth of 244 cm, resulting in the determination of the water content in the soil profile at depths of 15 to 259 cm below the soil surface. The water content in the top 15 cm was considered constant prior to each irrigation. The ratio of soil-to-shield counts detected by the neutron probe at each depth interval was converted to millimeters of water per 30.5 cm of soil depth. Soil moisture tensions were determined for each week throughout the entire rooting zone.

The quantity of water to be applied during the weekly irrigation for each treatment was determined according to the moisture content of the soil profile by calculating the amount of water required to bring the soil profile to field capacity immediately adjacent to the sprinkler line.

Evapotranspiration for each treatment after neutron probe access tubes had been installed was calculated using a water-balance method. The evapotranspiration for a given week was determined by calculating the change in soil moisture from the previous week to the current week and adding any precipitation or irrigation that had occurred during that week. Drainage was determined by subtracting the maximum ET (calculated using the equation of Kanemasu involving leaf area, air temperature, saturation vapor-pressure curves, and solar radiation) from the measured water loss for the period. Drainage was found to be nonexistent in every case.

RESULTS. The soybean yields presented in Table 2 show a contrast between the results for the two seasons. In 1976, there was a generally positive response from foliar fertilization; but in 1977, which had a favorable season with high yield levels, foliar fertilization caused a reduction in yield. Seed yields in 1976 as well as the responses from foliar fertilization increased in the direction of higher water application levels (A to E), at least in the plots irrigated during the flowering, pod-set, and grain-fill periods. Plots receiving irrigation water during 2 or only 1 of the periods showed more variable results in grain yields as well as responses from foliar feeding than those receiving irrigation in all 5 periods.

Table 2. Soybean Yields, Evapotranspiration and Yield Increase due to Foliar Fertilization in 1976 and 1977 at Each Water Application Level, Ft. Collins, Colorado

Water application level	1976 ET (mm)	1976 Bean yield (kg/ha) 0	1976 Bean yield (kg/ha) F	1976 Yield increase (kg/ha)	1977 ET (mm)	1977 Bean yield (kg/ha) 0	1977 Bean yield (kg/ha) F	1977 Yield increase (kg/ha)
		0III[a]				0III[a]		
A	237	880	933	53	303	1,562	1,439	-123
B	305	1,240	1,313	73	351	1,872	1,720	-152
C	376	1,721	2,064	343	392	2,002	1,774	-228
D	468	1,680	1,994	314	430	2,138	1,940	-198
E	534	1,560	1,945	385	484	1,976	2,093	117
		0I0I[a]				0I00[a]		
A	248	991	842	-149	301	1,405	1,516	111
B	284	926	1,194	268	319	1,628	1,819	191
C	338	1,263	1,594	331	346	2,024	1,963	-61
D	423	1,452	1,883	431	360	1,982	2,046	64
E	467	1,350	1,474	124	357	1,932	1,773	-159
		000I[a]				00II[a]		
A	254	1,319	1,117	-202	276	1,634	1,312	-322
B	273	1,266	1,377	111	305	2,211	1,818	-393
C	287	1,588	1,707	119	342	2,502	2,165	-337
D	296	1,360	1,537	117	370	2,728	2,338	-1,390
E	312	1,439	1,424	-15	431	2,962	2,743	-219
		00I0[a]				00I0[a]		
A	217	922	1,003	81	280	1,646	1,511	-135
B	237	1,020	1,254	234	307	2,166	1,971	-195
C	259	1,426	1,459	38	314	2,443	2,184	-259
D	284	1,320	1,836	516	331	2,362	2,121	-241
E	293	1,936	1,961	25	331	2,038	2,091	53

[a]Treatment designation, as shown in Table 1.

The findings at Fort Collins reflect the status of foliar fertilization elsewhere. The effects of many factors such as optimum time of day for application, removal of moisture stress levels, reduction of leaf burn, breakdown of N compounds and volatilization as NH_3, seasonal conditions, rainfall variety, and location are not fully understood. Inconsistent responses are accumulating for other field crops, such as maize and dry beans.

An overview of soybean research on the nutritional requirements of the plant under irrigation points to an urgent need for planning and international coordination.

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Soybean Yield Response to Multi-Limiting Soil Factors

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ABSTRACT: Fieldwork was carried out at the Agricultural Experiment Station of the Faculty of Agriculture, Cairo University, to study the combined effects of inoculation, irrigation, and fertilizer levels on the grain yield of soybeans grown on nonsaline, nonalkaline, alluvial clay loam soil. Treatments in this experiment included three levels each of nitrogen fertilizer, phosphorus fertilizer, and irrigation water. These were applied on one early maturing and one late-maturing soybean cultivar. Half of the planting of each cultivar was inoculated with *Rhizobium japonicum.*

In general, the highest yields of soybeans were obtained with inoculation, with the second level of irrigation (75 percent available water), with 143 kilograms of nitrogen per hectare, and with 31.2 kilograms of phosphorus per hectare.

SOYBEANS ARE KNOWN TO SUPPLY LARGE AMOUNTS OF HIGH-QUALITY PROTEIN that can be substituted for animal protein in the human diet. The crop was recently introduced into Egypt, but accurate information is still needed about the fertilization and irrigation requirements of soybeans in Egypt.

The judicious use of different fertilizers is beginning to overcome the problems of providing available plant nutrients. Adequate irrigation is considered necessary for high crop production. Although the response of a crop to different soil moisture regimes, in the range between the field capacity and the wilting percentage, is a matter of great agricultural importance, there is no information on the nature of the response.

Kramer (1949) and Israelson and Hansen (1962) reported that the soil moisture within the available range differs in its accessibility to plants. The term *readily available moisture* is used to refer to that portion of the available moisture that is most easily extracted by plants, and is approximately 75 percent of the total available moisture.

Rogers and Good (1952) and Shockley (1955) also support the hypothesis that 25 to 50 percent of the available moisture is not readily accessible for the maintenance of rapid crop growth. Growth reduction was associated with water tension in the substrate, to the reduction in hydration of the protoplasmic proteins and in apparent photosynthesis, and to an increase in the rate of respiration.

Maples and Keogh (1969) and Keogh and Maples (1974, 1976) studied the effect of different levels of nitrogen, phosphorus, and potassium fertilizers on soybean yields. Garcle et al. (1970) stated that inoculation, combined with nitrogen and phosphorus fertilizer, greatly increased soybean yields. The optimum rates of fertilizer per acre were 30-18-0 after wheat and 60-18-0 after sorghum.

Hinkle (1943), Gracia and Khalil (1948), Aladjem (1952), Stitt et al. (1955), and June and Smith (1959) found that by increasing the amount of phosphorus fertilizer, yields were increased and residual levels of available phosphorus were built up for the next crop. On the other hand, Russel (1961) reported that a phosphorus application that is larger than the amount required by the plant sometimes depresses seed and straw yields, especially in light-textured soils and during dry years. This result is attributed to the acceleration of the maturation process.

Ghorashy et al. (1972) showed that 85 kilograms of nitrogen per hectare, applied at planting or at the flowering stage of

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soybeans, produced the highest yield the first year, but that in the second year, bacterial inoculation produced the highest yield.

The current work studies the effect of a combination of irrigation, inoculation, and fertilization levels on soybean cultivars under Egyptian conditions.

MATERIALS AND METHODS

The current work was conducted at the experimental station farm of the Faculty of Agriculture, Cairo University, Cairo, Egypt, on an alluvial clay loam soil that is nonsaline and nonalkaline. The general characteristics of the investigated soil are presented in Table 1.

The research area was split into two large subdivisions. One subdivision was planted with the cultivar Clark, which is characterized by early maturity (four months), and the other subdivision with Hampton, which is characterized by late maturity (six months).

Treatments

The effect of the combination of *Rhizobium*, irrigation, and fertilizers was considered as follows:

1. *Rhizobium* (B):

   Half of each subdivision was inoculated with *Rhizobium japonicum* (B_1) and the other half was not (B_2). Inoculation was accomplished by soaking soybean seeds in a liquid culture containing *R. japonicum*. A six-day-old liquid culture of medium 79 (Allen 1959) of slow-growing *R. japonicum* was used at the rate of 10 milliliters of liquid per kilogram of seeds. The seeds were mixed with fine earth and planted by the herati method (planted in wet soil) immediately after inoculation.

2. Irrigation (I):

   Immediately after planting, irrigation water was applied to encourage bacterial activity. After emergence, the following irrigation regimes were initiated for both cultivars:

   I_1 = Irrigated with 100 percent available water (moisture ranging from 95 to 105 percent).
   I_2 = Irrigated with 75 percent available water (moisture ranging from 70 to 80 percent).
   I_3 = Irrigated with 50 percent available water (moisture ranging from 45 to 55 percent).

   Moisture was controlled by direct daily determinations of the moisture content at the depth of 0 to 60 centimeters (rooting zone). The application of water was controlled by adding the water through a gauge meter.

3. Fertilizer (nitrogen and phosphorus):

   Fertilizer, as nitrogen and phosphorus, was applied 30 days after planting, following irrigation. The treatments were nitrogen as ammonium sulfate (20.5 percent nitrogen) at rates of 0 kilogram (N_1), 74 kilograms (N_2), and 143 kilograms (N_3) of nitrogen per hectare; and phosphorus as superphosphate (6.98 percent phosphorus) at the rates of 0 kilogram (P_1), 15.6 kilograms (P_2), and 31.2 kilograms (P_3) of phosphorus per hectare.

Experimental Design

Treatments were applied in a factorial design (2 x 3 x 9) on each soybean cultivar in a completely randomized block design with three replications. The harvest area of each plot was 4 square meters and included three rows that were 2 meters long and 2 meters wide. To allow for the lateral seepage of water, 1 meter of border was included on the sides of each plot. The plots were planted in May, 1975. The climatological data are presented in Table 2.

Methods of Analysis

The soil was analyzed using the following techniques.

1. Particle-size analysis was done by the international method according to Piper (1950), using NH_4OH as the dispersing agent.
2. Calcium carbonate was measured by the Collins Calicimeter method according to Wright (1939).
3. Organic matter was measured by the modified Walkley's method according to Jackson (1967).
4. Total soluble salts were determined conductimetrically according to Jackson (1967).
5. Exchangeable cations were determined using Hissink's method as described by Piper (1950). Exchangeable calcium and magnesium were determined by the versinate method according to Jackson (1967). The sodium and potassium were determined photometrically, using a Perkin Elmer flamephotometer, according to Jackson (1967).
6. Soil moisture desorption curves were determined according to Shawky (1967).

7. The wilting percentage was determined using a pressure membrane according to Stakman and van de Harst (1962).
8. Nitrogen was measured by the Kjeldhl method according to Jackson (1967).
9. Phosphorus was measured by the Olsen method according to Jackson (1967).

RESULTS AND DISCUSSION

The yield of soybeans was increased on all inoculation treatments including B_1 alone, B_1 + NP, $B_1 + I_2$, B_1 + NP + I_1, and B_1 + NP + I_2 (Table 3). The highest yield was obtained when all three treatments--B_1, NP, and I were applied. *Rhizobium* inoculation was necessary to maximize the response in soybean seed yield from NP applications. Therefore, inoculation is an economical practice for increasing soybean yield for the following reasons:

(1) Inoculation treatments had a profound effect on the soybean crop. This effect is expected because inoculation is the main source of nitrogen in the soil. A supply of nitrogen for the plant can be obtained easily from this source (Weber, 1966) and the indirect effect of inoculation provides a suitable physical environment for plant growth (Weaver et al. 1972).
(2) Yield differences were significant, depending on the irrigation treatment used. The highest yield was obtained by using 100 percent available water (I_1). However, the economical use of water will depend on other factors that limit growth.
(3) There were significant differences between the N_3 nitrogen fertilizer treatments and both the N_2 and N_1 treatments; there was also a significant increase in yield between N_2 and N_1 treatments. This result indicates that soybeans give higher yields with higher levels of nitrogen. These results are in agreement with those of Izawa and Osi (1967) and Ishizuka (1970).
(4) Yield differences were not significant between the P_2 and P_1 treatments. However, there was a highly significant difference between the P_1 and P_0 treatments. The soybean plant requires phosphorus as a constituent of seeds, nucleoprotein, and ADP. Phosphorus is a main nutrient for bacterial activity as reported by Fletcher and Kurtz (1964), Anthony (1967), and Katti et al. (1970).

The interactions of I and B treatments with the soybean cultivar and nitrogen and phosphorus fertilizer were found to be as follows:

(1) The interactions between B and I treatments showed that the B_1 treatments gave the highest soybean yields. The highest values were recorded with the I_1 level (5,706 kilograms per feddan), followed by the I_2 treatment level (5,536 kilograms per feddan). Decreasing the irrigation level to 50 percent of the available water (I_3) resulted in a significant decrease in yield with or without inoculation. The conclusion is that at least the I_2 level of irrigation was needed for maximum *Rhizobium* activity because this irrigation level gave a suitable air-water balance for maximum growth and yield.
(2) The effect of interaction between B and N treatments on soybean yield was highly significant. When inoculated plots were fertilized at the highest level of nitrogen (N_3), the highest yield (6,638 kilograms per hectare) was obtained, followed by plots inoculated and treated at the N_2 level. The noninoculated plots that received the highest level of nitrogen (N_3) did not yield as much as plots that received the lowest inoculated treatment. Inoculation seems to be a major factor in producing higher yields. Higher yields were achieved on inoculated plots that also received an application of nitrogen fertilizer. This application may have enhanced the size of the nodules and may have caused additional bacterial activity, which maximized soybean yields.
(3) The interaction between B and P treatments shows significant differences. Inoculated plots treated at the P_1 level yielded significantly more soybeans than the P_0 plots, and the P_2 treated plants yielded significantly more than the P_1 treated plants. The yields of the noninoculated plots increased significantly with each increment of phosphorus fertilizer that was applied. Thus, the same conclusion can be reached for phosphorus as for nitrogen application on noninoculated plots. However, on inoculated plots, yield increases were significant only with the P_1 treatment. When phosphorus was applied, it affected the number of nodules and higher yields were obtained. This agrees with the results of Katti et al. (1970).

(4) The effect of the interaction between nitrogen levels and irrigation showed that the lowest yields with all three nitrogen treatments were on the plots that were irrigated at the I_3 level. Higher yields were obtained with the N_1 and N_2 fertilizer rates on the I_1 level, followed by the N_1 I_2 treatment.

(5) Yields were the same on both the plots treated with P_0 and P_1 that were irrigated at level I_1. Yields on the plots irrigated at the I_2 level were similar for both phosphorus treatments. Yields from all other treatments were significantly lower. Plots treated with phosphorus fertilizer always needed higher soil moisture to enhance the availability of the fertilizer.

(6) There were no significant differences among yields obtained with P_0 N_1, P_1 N_1 or P_1 N_0 treatments. Other plots treated with phosphorus and nitrogen had significantly lower yields. These data illustrate the need for adequate nitrogen and phosphorus fertilization for the highest yields. The triple interactions, shown by an analysis of variance, indicated that:

   (a) Yields for all noninoculated plots were significantly lower when compared with inoculated plots, regardless of the nitrogen and phosphorus treatment. The highest yields were on inoculated plots with the P_1 N_1, P_2 N_1, and P_1 N_0 treatments. This indicated that the P_1 level was sufficient to enhance bacterial activity and that the bacteria could then fix enough nitrogen to compensate for the application of nitrogen fertilizer.

   (b) The triple interaction between B, N, and I showed that either the I_1 or I_2 irrigation treatment, combined with the N_2 nitrogen fertilizer level, were the best treatments when the plots were inoculated. The noninoculated plots were significantly lower in yield than all nitrogen and irrigation treatments of inoculated plots except those that are irrigated at the I_3 level. The N_2 and N_1 nitrogen levels with the I_1 irrigation level gave the highest soybean yield for the noninoculated plots.

   (c) The triple interaction between *Rhizobium*, phosphorus, and irrigation showed that the I_2 irrigation level with either P_2 or P_1 were the best treatments for inoculated plots. The P_2 and P_1 treatments with the I_1 irrigation level resulted in the highest yield on the noninoculated plots. The same P_2 and P_1 treatments gave similar results on inoculated plots when they were irrigated at the I_3 level.

At the I_3 level of irrigation there was no significant difference in the nitrogen- and phosphorus-treated plots.

In general, the inoculation of soybean seeds before sowing with the proper *Rhizobium* strain can be recommended. Phosphorus fertilizers should be applied both as a source of phosphorus for the plant and to activate the vigor of and promote the increase in *Rhizobium* bacteria.

Nitrogen fertilizer can be applied not only to activate the nodules but also as a supplemental source of nitrogen, which is needed in adequate quantities for proper protein and fat formation in the seed.

The moisture level in the soil must not be reduced below 75 percent of the available water in order to achieve an adequate moisture level and to maintain a desirable air-water balance to produce higher soybean yields.

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Table 1. Selected Characteristics of the Soil in the Experiment Field, Cairo University, Giza, Egypt

Depth (cm)	Mechanical analysis, percentage[a] Coarse sand	Fine sand	Silt	Clay	Class texture[a]	O.M[b] (percentage)	$CaCO^c$ (percentage)	E.C.[d] mm.ha/cm at 25° C.	F.C.[e] (percentage)	W.P.[f] (percentage)
0-10	1.52	30.0	24.4	35.8	Clay loam	2.6	2.67	1.53	32.7	12.4
10-20	1.54	29.7	24.4	36.6	Clay loam	1.8	3.05	1.05	24.9	14.0
20-30	1.35	30.0	21.8	39.5	Clay	1.7	2.69	0.87	36.5	15.2
30-40	1.03	28.5	22.5	29.8	Clay	0.65	2.75	0.88	37.0	16.1
40-60	1.48	65.0	3.3	24.3	Sandy clay loam	0.05	2.84	1.35	25.8	7.4

Depth (cm)	C.E.C[g] Meg/100g	Exchangeable cations[h] Ca[h]	Mg[h] Meg/100g.	Na[h]	K[i]	Total[j] N (percentage)	Soluble[j] N ug/ml	Soluble[k] N ug/ml
0-10	46.8	24.2	14.5	8.8	0.29	0.10	100	19
10-20	42.8	20.5	13.6	9.6	0.23	0.09	95	20
20-30	44.9	22.5	12.6	10.2	0.25	0.06	45	18
30-40	40.6	18.8	13.3	8.2	0.23	0.06	80	19
40-60	21.0	10.3	4.8	8.7	0.24	0.03	35	18

[a]International method; dispersion with NH_4OH. Piper (1950).
[b]Modified Walkley's method. Jackson (1967).
[c]Collins Calcimeter method. Wright (1953).
[d]Soluble salts determined conductimetrically. Jackson (1967).
[e]Soil moisture desorption curves. Shawky (1967).
[f]Pressure membrane. Stakman and Vanderhast (1962).
[g]Hissink's method. Piper (1950), modified by Gohar (1954).
[h]Versinate method. Jackson (1967).
[i]Flame photometer. Jackson (1967).
[j]Kjehldahl method. Jackson (1967).
[k]Olsen method. Jackson (1967).

Table 2. Climatological Data from the Experiment Site, 30°02'N Latitude, 31°13'E Longitude, Cairo University, Giza, Egypt

Temperature, moisture, and wind	May	June	July	August	September	October
Mean monthly maximum temperature (C)	31.8	24.8	34.3	34.4	32.6	30.2
Mean monthly minimum temperature (C)	15.3	18.9	20.2	20.4	18.6	16.0
Mean monthly temperature (C)	23.3	26.5	27.0	26.8	25.3	22.8
Mean monthly relative humidity during day (percentage)	53.0	55.0	62.0	66.0	66.0	66.0
Mean monthly evaporation (mm/day)	17.8	18.4	15.7	13.5	12.1	10.7
Mean monthly precipitation (mm)	1.1	0.0	0.0	Trace	0.0	0.3
Computed mean monthly wind velocity at 2m height	2.4	2.7	2.9	2.7	2.1	--

Table 3. Soybean Yields (kg/ha) Under Varying Irrigation and Fertilizer Treatments as Affected by Rhizobium Inoculation at Cairo, Egypt (See footnotes for a description of the treatments.)

N	P	R	I_1	I_2 kg/ha	I_3	Average
N_0	P_0	B+	3,025	3,275	850	2,383
		B-	2,350	1,900	373	1,541
						1,962
	P_1	B+	8,325	9,125	1,350	6,267
		B-	4,200	3,025	675	2,633
						4,450
	P_2	B+	6,600	9,200	1,550	5,783
		B-	3,750	3,675	900	4,162
						4,973
N_1	P_0	B+	7,000	6,075	1,300	4,792
		B-	3,950	2,000	625	2,192
						3,492
	P_1	B+	7,475	8,250	1,475	5,733
		B-	4,425	3,325	900	2,883
						4,308
	P_2	B+	8,125	9,175	1,650	6,317
		B-	4,650	3,950	1,325	3,308
						4,813
N_2	P_0	B+	7,800	8,475	1,275	5,850
		B-	3,800	2,450	625	2,292
						4,071
	P_1	B+	9,300	9,225	1,475	6,667
		B-	4,650	3,900	950	3,167
						4,917
	P	B+	8,525	8,400	1,625	6,183
		B-	4,750	4,225	1,150	3,375
						4,779
Average		B+	7,353	7,911	1,394	5,553
		B-	4,058	3,161	836	2,685
Average for irrigation			5,706	5,536	1,115	4,119

N=nitrogen; P=phosphate; B+=*Rhizobium* present; B-=*Rhizobium* absent; I_1=irrigation at 95 to 100 percent; I_2=irrigation at 70 to 80 percent; I_3=irrigation at 45 to 55 percent.

Nitrogen Fixation and *Rhizobium japonicum* Carriers Under Irrigated Soil Conditions

Y.A. HAMDI

ABSTRACT: A review is presented covering the international activities on nitrogen fixation and *Rhizobium japonicum*. The topics discussed concerning *R. japonicum* include the: population density in soil; competition among strains; introduction into the soil (strain selection, types of inoculants, methods of inoculation, survival of rhizobia on inoculated seeds, size of inoculum, persistance of rhizobia in soil, and response to inoculation); nitrogen fixation during symbiosis as well as the amounts of nitrogen fixed; major factors that promote or inhibit N-fixation (nutritional factors, seed coat diffusates, temperature, moisture, acidity, salinity, pesticides, and biotic factors); and the residual nitrogen remaining in the soil after a soybean crop has been harvested.

THE RHIZOBIA-LEGUME ASSOCIATIONS are of considerable importance in agriculture. Among these, the symbiosis between *Rhizobium japonicum* and soybeans plays a significant role in the management of soybean production. The following review covers the recent information available on *R. japonicum* in terms of the population density in soil, competition among strains, introduction into the soil, nitrogen fixation as well as the amounts of nitrogen fixed, major factors that promote or inhibit nitrogen fixation by soybeans, and the residual nitrogen left in the soil after a soybean crop.

POPULATION DENSITY

The population density of *R. japonicum* in different soils of the world varies greatly. The soils of Egypt and Iraq are void of *R. japonicum* [Hamdi *et al.*, 1968; Ajam, 1974]. Certain fields in some countries lack the *R. japonicum* strains, e.g., the Marlboro field in the United States [Weber *et al.*, 1971] and the Darling Downs in Australia [Harty, 1974]. Even when *R. japonicum* is present, the density varies from soil to soil. The counts ranged from less than ten to more than a million cells per gram of soil in 52 soil samples taken in Iowa [Weaver *et al.*, 1972]. About 80 percent of the fields in which soybeans had been grown previously (at least once) had 10,000 cells per gram or more of *R. japonicum*.

Reliable counts of *R. japonicum* can be made by using the host plant in a biological assay in which dilutions made from a weighed quantity of soil are added to plants grown in a sterile medium in a Leonard jar system [Vincent, 1970]. The wild soybean (*Glycine ussuriensis* Regal Maack) was used as a test plant in dilution-nodulation frequency for counting bacteria [Brockwell *et al.*, 1975]. Weaver and Frederick [1972] developed a pouch technique to determine the most probable number of *R. japonicum* bacteria in the soil. Schmidt *et al.* [1968] described the fluorescent antibody approach to study these bacteria in the soil.

COMPETITION AMONG STRAINS

The same factors that enter into the capability of rhizobium to establish a viable population in the soil in competition with the biota already present come into play more intensively in the rhizosphere. These factors are augmented there by additional ones. Away from the root in the non-rhizosphere, the competition for substrate tends to favor other bacteria. In the rhizosphere, the competition for substrate seems to be at least somewhat in favor of the rhizobia.

According to reports, rhizobia are able to become well established in the rhizopheres of many legume and nonlegume plants. Apart from competition with other organisms in the rhizosphere, rhizobia must compete with each other not only for available

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substrate, but also for nodulation sites [Schmidt, 1978].

A large number of reports deal with the competitive ability of *R. japonicum* strains [Caldwell, 1969; Vest *et al.*, 1973; Diatloff and Brackwell, 1976]. Studies of competition require the identification of the strains to be tested. Usually, this has been done by using immunological techniques. Other studies, however, have used chlorosis-inducing strains of *R. japonicum* [Means *et al.*, 1961] and antibiotic-resistant marker strains [Schwinghamer and Dudman, 1973].

INTRODUCTION INTO THE SOIL

Strain Selection

Several criteria were identified by Date [1975] for use in selecting rhizobia strains for inoculants: (1) effectiveness in N_2 fixation and host specificity; (2) competitive ability in nodule formation and in persistance within the soil; (3) soil pH and pesticide tolerance as well as promptness of nodule formation at low or high temperatures and in the presence of high amounts of soil nitrogen; and (4) ease of growth and survival in a peat culture and the ability to survive on the inoculated seed.

Exceptional strains of soybean rhizobia were selected by Pedrosa *et al.* [1972]. These strains when grown for 7 to 8 days at 30°C in a liquid medium containing 400 parts per million of DL-aspargine were inhibited 60 percent more than others grown in a medium containing 100 ppm of DL-aspargine. Normal strains were inhibited much less, or not at all, when the higher concentration was used.

Types of Inoculants

According to Burton [1976], six types of soybean inoculants are available in the United States: (1) moist peat powder; (2) liquid or broth; (3) agar or bottle culture; (4) oil-dried rhizobia in vermiculite; (5) lyophilized rhizobia in talc; and (6) a granular-type peat inoculant designed for direct application to the soil. A high-quality inoculant will provide 10^5 to 10^6 rhizobia cells per seed.

Many attempts were made to develop other carriers suitable for rhizobia, for example: soil plus materials such as wood charcoal, coir dust (from the outer husk of the coconut), soybean-meal or plant compost; peat or soil ammended with material such as alfalfa meal or ground straw; Nile silt with minerals; decomposed maize cobs; finely ground bugasse (the residue from sugar cane pulp); coal-based inoculants; decomposed date palm leaves, alfalfa plants, and city refuse; peat moss or lignite with 1 percent soybean powder; rice husks; filter mud; and cellulose powder. All of these attempts were justified by the lack of a suitable local supply of peat and because the materials listed were cheap and were readily available.

Methods of Inoculation

SLURRY METHOD FOR SOLID BASE CARRIERS. Slurry, as usually prepared, contains 4.4 grams of peat per 9 milliliters of slurry, with sucrose or maltose (10 to 15 percent) used to improve the survival of rhizobia on the seeds (Burton, 1964). That quantity will treat 1 kilogram of seed. Gum arabic in combination with a peat base inoculum was beneficial in increasing the longevity of rhizobia.

GRANULAR INOCULANT. Granulated inoculant has been developed recently [Burton, 1976]. Using this method, chemical treatments can be applied to the seeds without fear of killing the rhizobia. Granular inoculation is beneficial when soybeans are grown in hot, sandy soils or when the seeds are sown from the air.

LIQUID INOCULANTS. Hely *et al.* [1976] described a pressure-controlled, spray-on technique for inoculating legumes on a commercial scale. The technique was developed to place suspensions of bacteria accurately into the soil beneath seeds placed in sod-sown rows and to apply greater amounts of inoculant than can be carried on the seed by using present methods.

PREINOCULATION METHOD. "Preinoculation" is a term applied to the inoculation of legume seeds with rhizobia before selling them to the farmer, implying a storage period for the inoculated seed before sowing. Thompson *et al.* [1975] reviewed the preinoculation of legume seeds in the United States and Australia. They recommended: (1) displaying the preparation date on all batches of preinoculated seeds; (2) acquainting retailers with the principles governing the storage of inoculated seed; and (3) adhering carefully to an expiration period of one month.

SEED PELLETING. Pelleting legume seed with lime provides a way of protecting rhizobia from acid soils and fertilizers. Originally, the seed was coated with an adhesive and finely divided $CaCO_3$; then, the rhizobia were coated on the outside of the lime layer. Several refinements were achieved in this technique, such as using different adhesives and coating

materials [Brockwell, 1962; Herridge and Roughley, 1974].

Pelleting the soybean seed with rock phosphate or lime [Iswaran and Jauhri, 1969] or with Ca-humate [Iswaran and Chhonkar, 1973] after inoculation with rhizobia markedly increased the number of nodules per plant and the production of plant dry matter.

In acid soils, pelleting soybean seeds with lime gave the best nodulation and yields in the Phillipines [Bandoja *et al.*, 1974]. Using rock phosphate or lime for pelleting increased nodulation and yields in Nigeria with a soil of pH 4.5; also, in Sierra Leone with a soil of pH 4.6 [Danson and Nangju, 1975].

Bacteria Survival on Inoculated Seeds

Soybean rhizobia survive on the seed only for a short time. Therefore, it is important to sow the inoculated seed immediately in order to ensure maximum survival of the bacteria. On the other hand, when larger quantities of soybean seeds are inoculated and a longer time is required for planting, the use of gum arabic is preferable for better nodulation.

Quantity of Bacteria in the Inoculant

Generally speaking, large numbers of rhizobia on the seed favor survival before planting as well as rhizobia multiplication in the rhizosphere during early nodulation. Several workers studied the relationship between the number of rhizobia on seed and nodulation. Burton [1968] indicated that nodulation on tap roots is closely related to the level of bacteria on the seed. When less than 10^5 rhizobia per seed are present at planting, few plants will have nodules on the tap roots. The largest plant size and number of nodules were obtained with 1.5 to 3 x 10^6 rhizobia per seed. The plants were greener and produced a significantly larger seed yield. The lower level of 7.5 x 10^4 rhizobia per seed was not adequate even under almost ideal conditions.

The soils of Egypt are void of *R. japonicum.* There, 81 to 93 percent of the plants formed nodules when inoculated with 2.8 x 10^6 rhizobia per seed. However, only 47 to 57 percent of plants grown from seeds inoculated with 2.8 x 10^4 cells per seed formed nodules [Hamdi *et al.*, 1974].

In soils containing natural rhizobia populations, high rates of inoculation are required to cause a population shift in favor of the introduced strain. An ultra inoculation on soybeans of 2 x 10^9 cells per seed has been suggested [Kapusta and Rouwenhorst, 1969 . A rate of a thousand times the soil population of rhizobia was required to establish 50 percent of the total nodules from the introduced strain [Weaver and Frederick, 1974b].

Persistence of Rhizobia in the Soil

The persistence of strains of rhizobia following their introduction into the soil has long been recognized as an important ecological problem. Enriching the soil with specific strains of *R. japonicum* boosted nodule numbers for only a short time in 4 varieties of soybeans in India [Kabi, 1976]. Exotic strains lost their nodulating ability over a 3-year period.

Bohlool and Schmidt [1973] used the fluorescent antibody technique for a time study of the persistence of strain 110 introduced into uninoculated soil by burying glass microscope slides coated with the rhizobia. In all 4 soils tested, 5 cells persisted for 2 to 4 months, even though the number of bacteria was reduced drastically over the period.

Response to Inoculation

NODULATION. The inoculation of soybeans to be grown in rhizobia-free soil will ensure nodulation when good conditions prevail [Hamdi *et al.*, 1974]. However, strains of *R. japonicum* applied at different rates and by different methods varied greatly in the proportion of nodules they formed on soybeans grown in soil containing other effective strains of rhizobia. The percentage of nodules produced by strains applied at the standard inoculation rate averaged only 5 percent [Johnson *et al.* 1976]. Raising the rate also increased the proportion of nodules produced by some strains, but not by others. In another study, 5 to 10 percent of the nodules on plants grown in a field with an established population of *R. japonicum* bacteria were derived from the bacteria strains introduced into the soil [Caldwell and Vest, 1970].

Weaver and Frederick [1974] indicated that in soils containing 1 x 10^3 or more rhizobia per gram, plants are not likely to be nodulated extensively by rhizobia applied at 1 x 10^4 cells per seed. Under field conditions [Weaver and Frederick, 1974b], a rate of 3.3 x 10^6 rhizobia per seed produced 65 percent of nodules on plants in soils containing less than 12 rhizobia per gram. In soils containing 10^3 rhizobia per gram, the same inoculation rate produced 35 percent of the plant nodules. Weaver and Frederick suggested that an inoculation rate 1,000 times the soil population must

be used to competitively establish 50 percent of the nodules on plants.

Inoculant mixed with moist builder's sand and drilled into the row at 10 times the recommended rate before planting produced only 63 percent as many plant nodules as a peat inoculant applied at a similar rate [Hinson, 1969]. The proportion of nodules formed by an inoculant strain has been increased by applying large quantities of inoculant directly into the row at planting time [Kapusta and Rouwenhorst, 1973].

Boonkerd *et al.* [1978] evaluated the inoculation of soybeans by rhizobia strains 62, 76, and 110 applied as peat or liquid inoculant at different rates of 1 and 10 times the initial rate with peat and 1, 10, and 100 times with liquid inoculant. Inoculation by either method or with any rate did not affect nodulation or plant growth. However, when the level of strains 62 and 110 in broth was 10 and 100 times the initial rate, the recovery of the applied strain from the soil increased. Peat inoculant applied at the 10-times rate did not change the distribution of strains in nodules appreciably.

Other factors than the quantity of inoculant govern the nodulation response of soybeans. Certain varieties of soybeans are more difficult to nodulate effectively than others [Vest *et al.*, 1973]. Burton [1976] indicated that Norman and Bragg soybeans were not responsive to inoculation.

Four genes affecting symbiosis have been described in soybeans. The homozygote $rj_i\ rj_i$ (formerly, *no no* or *n n*) was found to be resistant to nodulation [Williams and Lynch, 1954; Caldwell, 1966]. Roots of the $rj_i\ rj_i$ plants secreted a substance that inhibited the nodulation of adjacent normal soybean or clover plants [Eelkan, 1962]. However, Eskew and Schardor [1977] showed that the nodulation inhibitor was not associated with the rj_i gene.

The rj_2 gene is dominant and causes the ineffective response to some strains of *R. japonicum*. Plants formed only small nodules with white interiors. This reaction was first observed with the Hardee variety [Caldwell, 1966; Caldwell, *et al.*, 1966]. The rj_2 gene caused an ineffective response by Hardee to rhizobia strain 33 according to Vest [1970] who also observed the formation of many small, white, nodule-like structures.

The rj_4 gene was reported as being dominant and as causing an ineffective response [Vest and Caldwell, 1972]. A strain-specific gene in the Geduld variety is thought to be associated with rhizobia incompatability [Balasundaram *et al.*, 1972].

YIELD INCREASE. Inoculating soybeans with effective strains of *R. japonicum* may increase yields when the bacteria are not present in the soil. Whether inoculation is beneficial when seeds are planted in soils populated with effective rhizobia is in doubt. No significant response to inoculation was obtained when soybeans were planted in soils containing rhizobium bacteria [Ham *et al.*, 1974; Rabb, 1976].

The response in terms of soybean yields to inoculation has been reported in different parts of the world. Subba Roa, and Balasundaram [1971] observed a significant increase of 14.3 to 25.7 percent in yields, depending on location in India. Hera [1976] obtained yield gains of 16 to 78 percent through inoculating soybeans in different soil types in Romania. Raicheva [1976] showed that inoculating soybeans increased yield much more than applying 80 kg/ha of mineral nitrogen in Bulgaria.

A significant response to soybean inoculation has also been reported in Iraq, Egypt, Cuba, Nigeria, Tanzania, Ghana, Sierra Leone, Cameroon, the Democratic Republic of Madagascar, Zaire, Rwanda, Kenya, the Phillipines, Malaysia, and Thailand.

NITROGEN-FIXATION DURING SYMBIOSIS

Nitrogen Fixation

Many aspects of symbiotic nitrogen have been studied using the acetylene-reduction method. Although symbiotic nitrogen fixation by nodulated soybeans has been found as early as 14 days after planting [Hardy *et al.*, 1971], the major portion of nitrogen is fixed between the flowering stage and the formation of green beans, 30 to 85 days after planting [Hardy *et al.*, 1971; Weber *et al.*, 1971].

Klucas [1974], using the acetylene-reduction technique, showed that nitrogenase activity decreased 60 percent between 58 and 65 days after planting with Beeson soybeans and between 68 to 75 days with Galland.

The seasonal profile of N_2-fixing activity (using the acetylene-reduction technique) showed that initially, the activity of tap-root nodules was greater than that of nodules on the lateral roots; however, the lateral-root nodules ultimately exhibited higher rates [Sloger *et al.*, 1975]. Estimates showed that nodules on lateral roots contributed about 60 percent to the amount of nitrogen fixed; tap-root nodules, about 40 percent. Also, about 38 percent of the lateral-root nodules were lost during the process of digging plants out of the soil to obtain nodule counts.

In another study, maximum nitrate utilization occurred at full bloom. Symbiotic N_2-fixation (using the acetylene-reduction method) peaked some 3 weeks later during pod-fill. Correlation of seed yield with nitrogen fixation, combined nitrogen, or both showed that symbiotic N_2-fixation and nitrate utilization appeared to be essential for maximum soybean yields [Harper, 1974].

Measurements of relative efficiency (RE) can be made by using the equation

$$RE = 1 - \frac{\text{rate of } H_2 \text{ evolution in air}}{\text{rate of acetylene reduction}}.$$

In the nitrogenase complex, measurements of RE in energy utilization showed that under controlled conditions for bacteria, temperature, and light, the efficiency of soybean nodules ranged from 0.44 to 1.0 [Evans *et al.*, 1977]. Selected *R. japonicum* strains 3-I-1b-6, 3-I-1b-142, and 3-I-1b-143 produced nodules of Anoka soybeans that evolved little or no hydrogen in the air. Relative efficiencies of near 1 were recorded for these strains. Plants grown with these strains produced 24 percent more dry matter and fixed 31 percent more nitrogen than other commonly used strains.

Amounts of Nitrogen Fixed

Estimates on the quantities of nitrogen fixed vary according to the evironmental conditions, efficiency of rhizobia strains, method of estimation, and so on. In Egypt, soybeans fixed 42 kg of N/ha [Rizk, 1966]. Vest [1971] showed that Delmar soybeans fixed 121 kg of N/ha, which was about 52 percent of the total nitrogen found in the beans.

Estimates based on the acetylene-reduction technique showed that the amount of nitrogen fixed in the Kent variety was 74 to 82 kg of N/ha [Hardy *et al.*, 1968]. Weber *et al.* [1971] calculated the amount of N fixed at 100 kilograms per hectare. In another report, [Sloger *et al.*, 1975], soybeans were reported to fix 84 kg of N/ha, about a third of the plant and seed N, with a yield of 2,219 kilograms per hectare. Accounting for N_2-fixing activity from lost nodules, the estimate rose to 103 kg of N/ha, or about 40 percent of the plant and seed nitrogen.

Calculations of the amount of nitrogen fixed on the basis of the total N content of field-grown nodulating and non-nodulating isolines showed that 55 kg of N/ha was fixed symbiotically by field-grown soybeans [Ham, 1975].

MAJOR FACTORS PROMOTING OR INHIBITING N-FIXATION IN SOYBEANS

The amount of N_2 fixed by the legume-rhizobia symbiotic system is influenced by many chemical and environmental factors. These may affect the host plant or the rhizobia bacteria *per se*, as well as the development and effective function of the nodules.

Nutritional Factors

Nutritional factors may limit N_2-fixation by the legume-rhizobia symbiotic system in several ways. Nutrition may restrict the development of a population of free-living rhizobia in the rhizosphere, the growth of the host plant, or nodulation itself and may also impair the functioning of the nodules.

CARBON. The main pathway for carbon assimilation includes the acquisition of atmospheric carbon dioxide through photosynthesis. Ample evidence is available that a supply of photosynthetic products must be provided to the nodules for nitrogen fixation.

The relationships between the photosynthetic source and sink components were studied by Lawn and Brun [1974]. The effects of the following variables were studied for the soybean varieties Chippewa 64 and Clay: (1) supplemental light below the canopy, (2) 50 percent depodding; (3) 25 percent shade; and (4) 60 percent defoliation on nitrogen fixation. Acetylene-reduction activity increased during flowering, reached a maximum near the end of flowering, and then declined markedly during pod-filling. The decline in acetylene-reduction activity was attributed to a drop in specific activity within the nodules. Supplemental light and depodding maintained a level of specific activity in the nodules above that in the control plants. On the other hand, treatments designed to reduce the source-to-sink ratio of shading to defoliation decreased the specific activity of the nodules. Supplemental light also increased the weight and protein content of the seed. Shading and defoliation reduced these factors in both varieties. The conclusion was that the decline in N-fixation during pod-filling was caused by an inadequate supply of photosynthate to the nodules.

Ching *et al.* [1975] showed that the nitrogenase activity dropped by 50 percent one day after the daylength of the soybean plants

was decreased. The reduction was accompanied by a drop of 60 percent in sucrose, 70 percent in adenosine triphosphate (ATP), and 55 percent in the production of ATP-ADP (adenosine diphosphate).

Hardy and Havelka [1976] showed that enriching the soybean plants with carbon dioxide caused an increase in nitrogen fixation of more than five-fold by doubling specific activity in the nodules, doubling the average nodule mass, and extending the exponential growth phase. The nitrogen contribution was more than 80 percent from N_2 for CO_2-enriched plants compared to 25 percent from control plants not treated with CO_2 gas.

COMBINED NITROGEN. According to reports, combined nitrogen decreases the nodulation of legumes and reduces N_2-fixation. The degree of inhibition depends on many factors, including the concentration and form of the nitrogen applied, the time of application, and the rhizobia strains used.

Beard and Hoover [1977] reported that soybean plants grown with no nitrogen fertilizer showed yellowing during early growth, but became dark green later in the season and exhibited no significant differences in yields. The number of nodules was reduced when nitrogen was added at planting time but not when nitrogen was applied at the flowering stage.

Hatfield *et al.* [1974] indicated the importance of soil nitrogen for the initial growth of soybeans, even when inoculated. The dry weight of inoculated plants receiving N at 0 and 2 weeks was significantly lower than that of inoculated plants receiving N at 4 and 6 weeks. The dry weight of noninoculated plants receiving N at 6 weeks was the same as for inoculated plants receiving N at 4 and 6 weeks.

Olsen *et al.* [1975] showed that the yield of Bragg soybeans was not increased by nitrogen fertilizers applied to the surface of the soil at 112 and 224 kg of N per hectare. The yield was increased when N was applied at 448 kg per hectare. Nodulation was reduced by applying nitrogen on a soil with a relatively low content of organic matter, but had less effect on a soil with a higher content of organic matter.

Comparisons between nodulating and non-nodulating isolines of soybean showed that even the application of 200 kg of N/ha to the non-nodulating plants did not produce yields equal to the nodulated isolines [Singh *et al.*, 1974]. The total nitrogen supplied through nodulation was equivalent to 100 kg of N per hectare. In another study, the grain yields of nodulating isolines with no nitrogen applied equalled that of the non-nodulating isolines treated with N up to 224 of kg/ha [Bhangoo and Albritton, 1976]. Symbiotic nitrogen fixation decreased to almost zero when nitrogen applications exceeded 224 kilograms per hectare.

The use of anhydrous ammonia did not significantly affect soybean yields but did reduce nitrogen fixation and nodule mass. The depression of the nodule mass was overcome by adding organic matter [Criswell *et al.*, 1976]. Nitrate placed in the lower 10 centimeters of a 30.5-cm soil column allowed greater nitrogen uptake by the roots and did not impair nodulation, as did nitrate dispersed throughout the column [Harper and Cooper, 1971].

Harper [1974], in an experiment using gravel as the soil medium, showed excellent nodulation of soybenas at a 25-percent concentration of a modified Hoagland nutrient solution, fair nodulation at a 50-percent concentration, and no nodulation at a high concentration.

Williamson and Diatloff [1975] examined the effect of urea applied at rates of up to 134 kg/ha of N on soybeans in Queensland. Nodulation and nitrogen fertilizer increased the seed size and nitrogen content of the seed in soils free of *R. japonicum*, but nitrogen fertilizer had little effect on these characteristics in soils containing *R. japonicum*. Nitrogen fertilizer had a depressing effect on nodulation in soils with decreasing moisture and a high temperature. In soils with *R. japonicum*, this depressing effect of nitrogen was comparatively small.

Vigue *et al.* [1977] showed that in a hydroponic culture containing up to 18 micromoles of nitrogen, effective nodule development and functioning occurred. Growing plants in a urea solution proved to be a convenient hydroponic method for producing vigorously nodulated soybeans capable of fixing 27 to 71 percent of the total plant nitrogen.

OTHER NUTRIENTS. Soybeans require nutrients such as phosphorus, potassium, calcium, magnesium, sulfur, manganese, iron, molybdenum, zinc, boron, and cupper. Lucas and Knezek [1972] reported high response of soybeans to Fe and Mn, medium response to Zn and Mo, and no response to Cu and B—all under soil conditions in which those elements were deficient.

Soybean plants grown in acid soils in Brazil showed a sensitivity to soil Mn [Franco and Dobereiner, 1971]. The number, weight, and size of the nodules were affected by Mn toxicity.

Kapur *et al.*, [1975] showed that $ZnSO_4$ at 5 and 10 ppm increased the yield and nitrogen fixation of soybeans. Significant

increases in the leghaemoglobin content and number of bacteria in nodules were recorded, but the amount of nitrogen fixed declined with heavier application of zinc.

Seed-coat Diffusates

Soybean seeds produce substances inhibitory to strains of *R. japonicum*. The degree of inhibition varied markedly by the bacteria strain and soybean variety [Abd-El Ghaffar, 1976]. Toxicity from soybean seeds can be eliminated by soaking the seed for 4 hours [El-Mallah, 1978].

Temperature affects all stages of the symbiotic association between rhizobia and legumes. High soil temperatures coupled with soil alkalinity resulted in the failure of soybeans to nodulate in Queensland [Diatloff, 1970]. The optimum root temperature for N-fixation by soybeans was reported as 27°C by Kuo and Boersma [1971].

Dart *et al.* [1976] inoculated Chippewa soybeans with *R. japonicum* strains CB-1809, Smlb, or CC-705 and grew the plants at 21°, 27°, and 33°C (daytime temperatures) in controlled-environment cabinets. There were only small differences in nitrogen fixation between strains at 21°C; but at 27°C and especially at 33°C, strain Smlb was the most effective. The strain CC-705 was as effective as CB-1809 in forming red nodules at 27° and 33° C. The nodules exhibited some nitrogenase activity, but fixed little nitrogen.

Weber and Miller [1972] reported that the serogroups which caused the majority of nodules on soybeans at 30°C formed very few nodules at 10° or 15°C, while the serogroups dominant at the low temperatures were not effective in developing nodules at 30° Celsius.

Moisture

Ecologically, rhizobia must be surrounded by a water film in which the solutes are not concentrated enough to pose osmotic problems for the cell. Too little water, rather than too much, is the threat to survival and function. Extreme drying is accompanied by increased osmotic pressure of the soil solution; and if the desiccation is caused by elevated temperatures, this factor interacts, too [Schmidt, 1978].

There are no reports in the literature concerning the effect of moisture content on the movement of soybean rhizobia. However, the zones of movement for *R. trifolii* were sharply decreased by higher water tensions. This movement ceased when the water-filled pores of soil became discontinuous [Hamdi, 1971].

Water supply and stress affect the fixation of nitrogen by soybean nodules. Irreversible changes occur in detached nodules when their fresh weight is reduced to below 80 percent of their maximum rigidity value [Sprent, 1971a]. Water stress affects the fine structure of these detached nodules [Sprent, 1971b]. A loss of about 30 percent in the fresh weight results in a breakdown of the cytoplasm into approximately spherical subunits, some of which are coated with ribosomes. Organelles such as nuclei and mitochondria retain their structure longer than the rest of the cytoplasm. Lenticles (ridges on the surface of the nodules that permit free gasses to pass in and out of the nodules) collapse under water stress. Under water-logged conditions lenticles produce large masses of loosely packed cells [Pankhurst and Sprent, 1975].

Sprent [1971b] showed that water stress reduced nitrogen fixation by soybean plants grown in sand pots. If the nodules retained some activity, recovery after watering was normally complete within an hour. Using tritiated water (^{3}HOH), the fact was confirmed that water could be withdrawn by nodules while *en route* from the root to the shoot in soybean plants.

Soil Acidity

Acidity is likely to be a major factor restricting the persistence of rhizobia in soil, although species differ considerably in their sensitivity. *Rhizobium mehloti* is very acid-sensitive, but *R. japonicum* can tolerate an acid pH as low as 3.5 [Vincent, 1965].

The effect of soil acidity on the growth and nutrition of legumes may be attributed to the direct effects of pH *per se*, deficiencies of calcium and molybdenum, and toxicities of manganese and aluminum. Dobereiner [1974] indicated that aluminum toxicity limits nodulation and nitrogen fixation more than it affects plant growth.

Salinity

The growth of *R. japonicum* is strongly retarded in media containing 0.008 *M* NaCl and does not grow with 0.16 *M* NaCl [Wilson and Norvis, 1970]. Different strains of *R. japonicum* exhibited varying tolerances to concentrations of 0.1, 0.2, 0.3, 0.5, 1, 2, 5, and 10 percent of sodium chloride in liquid media. Growth was greatly reduced at 0.5 percent and at higher levels of sodium chloride [Ala, 1976].

Soybeans are sensitive to saline soils containing soluble salts above 7 millimoles per centimeter [Abu Shakra, 1975]. Abd El-Ghaffar

[1976] showed a negative correlation between the salt concentration and the number of nodules on the roots and between the dry weight and the content of soybean plants grown in soils with different sodium chloride and Na_2SO_4 concentrations. Plant growth was inhibited when the concentration of NaCl was at 0.8 percent or higher and when that of Na_2SO_4 was 1.5 percent or more.

Pesticides

In soybean fields the pesticides used may interfere with the development of *R. japonicum* and with the symbiosis of the rhizobia-soybean system. With lindane (zineb), higher levels of application increased the number of nodules and the amount of dry matter produced and enhanced the seed yield as well as the nitrogen uptake [Blasubramanian *et al.*, 1974].

Fungicides vary in their effect on soybean rhizobia. Thiram had no adverse effect. Carboxin had little effect when seeds were planted within 4 hours of the inoculation. Captan was less toxic to rhizobia than PCNB but reduced the number of nodules on the tap root [Curley and Burton, 1975]. Dithane Z-78 (zineb), Aureofungin, and Ceresan (ethylmercury chloride) allowed the rhizobia to produce a moderate number of nodules, although fewer than when the fungicides were absent. Nodulation was greatly reduced by the use of Monosan. Thiram completely checked nodulation [Wankhede and Bhide, 1972]. Plant dry weight and nitrogen content were reduced significantly by the use of Phygon (dichlone) at 3 percent, but not by Spergon. Orthocide (captan) at a concentration of 0.3 percent was stimulating [Hamdi *et al.*, 1974].

Different rates of herbicides had detrimental effects on the nodulation of soybeans in 4 of the 5 soils used in greenhouse studies [Dunigan *et al.*, 1972]. The dry weight of the nodules was affected more than was the total number of nodules. A 3-year field study did not reveal detrimental effects from any of the herbicides used.

Biotic Factors

Many hypotheses have been advanced to account for the failure of rhizobia to colonize readily or to explain the population decline when bacteria are deliberately added to the soil. Actinomycetes, fungi, mycorrhizae phage, *Bdellavibrio*, protozoa, and nematodes may inhibit, stimulate, prey upon, or parasitize rhizobia.

Damargi and Johnson [1966] showed that the actinomycete isolate E1 antagonized *R. japonicum* strain 76. Isolate E8 was antagonistic to all strains.

In autoclaved soil, the ability of rhizobia to infect Kent soybeans was evaluated in the presence of actinomycete isolates. The reduction in nodule numbers was 53 and 35 percent, respectively, when actinomycete E8 was introduced into the soil 28 days before planting and at the time of planting.

Orellana *et al.* [1976] showed that *Rhizoctonia* fungus caused a decrease of 63 percent in the amount of nitrogen fixed per plant in inoculated Lee soybeans. At 30°C, nodulation from *R. japonicum* increased. *Rhizoctonia solani* had a lesser effect on nitrogen fixation at the same temperature.

Mycorrhizal infection, however, improved nodulation and soybean yields. Introducing *Endogone* (VA mycorrhiza) into small field plots of soybeans overcame the deleterious effect of fumigation on plant growth in the absence of a large application of phosphate fertilizer [Ross and Harper, 1970]. Schenk and Hinson [1973] showed that inoculation with *Endogone* significantly improved seed yield and other traits of the nodulating soybean isoline Hardee but not that of the non-nodulating isoline.

Bacteriophage has been variously emphasized as a potential biofactor. Vincent [1965] indicated that despite the voluminous literature on rhizobiophage, however, the practical significance of phage as a factor acting against the survival and functioning of the rhizosphere in the soil has yet to be demonstrated.

Bdellavibrio is a soil inhabitant that probably exists in nature as an obligate parasite. Strains feeding on *R. meliloti*, *R. trifolii*, and cowpea rhizobia have been found in many soils. When these bacteria are provided with cowpea rhizobia in culture, they kill many host cells. So the same vibrios might be responsible for the death of rhizobia in soil [Alexander, 1975]. Whether *Bdellavibrio* has a deleterious effect on *R. japonicum* in soil remains to be determined.

Protozoa are suspected as being predators of rhizobia in the soil. Alexander [1975] reported that the number of *R. japonicum* bacteria decreased in the soil as a result of activity by protoza. Each protozoan appears to consume thousands of bacteria. After 12 days, though, 6.3×10^7 rhizobia per grain remained. Further, Alexander showed that the ciliate *Tetrahymena* eliminated *R. japonicum* if multiplication of the rhizobia is prevented by using chloramphenicol. *Tetrahymena* feeding on rhizobia in the absence of the inhibitor did not reduce the number of rhizobia below 10^6 cells/ml, but did reduce the number of nonmultiplying rhizobia to 270 cells per milliliter.

Nematodes interfere with nodulation and the growth of soybean plants. Lehman *et al.* [1970] showed that soybeans infected with

H. glycines (race 1) from Wilmington, North Carolina, showed reduced nodulation and N-fixation, whereas plants infected with other races did not show those symptoms. When cyst nematodes were injected into the soil 14 days after rhizobia inoculation, only a slight to moderate inhibition of nodulation occurred [Barker *et al.*, 1972]. The greatest inhibition was observed when soybeans were inoculated simultaneously with *R. japonicum* and race 1 of the soybean cyst nematode.

RESIDUAL SOIL N AFTER GROWING SOYBEANS

Henzell and Vallis [1975] reviewed the work done on the transfer of nitrogen legumes to other crops. The concentration of nitrogen in legume residues varies widely, influencing greatly the amount of nitrogen transferred. The initial flush of mineralization from legume residues, which provides most of the transfer, relates directly to the percentage of nitrogen in these residues and to the quantity of such residues. If the parts of the plant removed from the land contain most of the legume nitrogen, there can be little mineralization of nitrogen for use by another crop.

With soybeans, Rizk [1966] showed a gain in soil N of 59 kg/ha after a soybean crop in Egypt. Schroder and Hinson [1974] grew nodulating and non-nodulating soybeans in rotation with winter rye and in mixtures with rye to study the contribution of the legumes to soil nitrogen. Their results support the idea that the roots of nodulating soybeans leave significant amounts of nitrogen in the soil.

Saxena and Tilak [1975] showed that by inoculating soybeans, yields were increased from 73 to 94 percent. With no application of fertilizer N, the yield of wheat following an inoculated crop of soybeans was more than 65 percent higher than with wheat following a soybean crop that had not been inoculated. The response was equivalent to about 30 kg of N/ha as fertilizer.

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Evaluation of Soybean Inoculant Types and Rates Under Dry and Irrigated Field Conditions

R.S. SMITH AND G.A. DEL RIO ESCURRA

ABSTRACT: High soil temperatures and low soil moisture stresses for 7 days after planting were utilized to evaluate inoculant types and rates on soybeans grown in a *Rhizobium japonicum*-free soil in Puerto Rico. All inoculant treatments were evaluated under stress conditions in the half of the experiment that did not receive rain or irrigation and that had a moisture level below the wilting point for the first 7 days. During this period in the dry section, the soil temperature at 2.5 cm reached a maximum of 38° to 40° C. All inoculant treatments were also evaluated in the half of the experiment that was irrigated to provide a moisture level near optimum. This moisture reduced the maximum soil temperatures at 2.5 cm to between 31° and 35° centigrade.

The granular soil inoculant was the best treatment in producing tap root nodules, total number of nodules, and nodule dry weight per plant after both 32 and 98 days. Liquid soil inoculant in the seed furrow and liquid placed 2.5 cm below the seed were generally better than all remaining treatments, i.e., liquid 5.0 cm below the seed, liquid 7.5 cm below the seed, and peat powder inoculant applied to the seed.

Applying all inoculants at 10 times the normal rate produced a consistent but not significant increase in nodulation parameters when each inoculant treatment was compared to its standard rate, except for the granular soil inoculant where significant nodulation increases were observed in 8 of the 12 evaluations.

Nodulation under dry and irrigated conditions was compared by totaling the values for all treatments in both moisture regimes. The number of taproot nodules, total number of nodules, and the nodule dry weight per plant were significantly increased on both sampling dates under irrigation compared to the dry condition. All nodulation values were at least 3 times better under irrigation. The number of taproot nodules was 6 times larger under irrigation than in the dry section at the 98-day sampling, due to the lack of increase in taproot nodules under the dry condition between the 32- and 98-day sampling. With irrigation, the taproot nodulation had doubled during the period.

HIGH SOIL TEMPERATURES AND DESSICATION FROM low soil moisture have been postulated as possible causes of nodulation failure. Diatloff [1970] recorded a soil temperature of 40° C for 4 hours in a moist soybean seed zone with some decline in nodulation evident, although this was by no means critical to subsequent nodulation. However, if high-temperature effects are superimposed on another stress factor, such as dessication, a nodulation failure would become more likely. Iswaran, Sundara-Rao, Jauhri, and Magu [1970] observed the rapid death of *Rhizobium japonicum* at 40° C when added to either soil or peat with no worthwhile recovery after 4 weeks of storage. At 28° and 35° C, peat was superior to the soil as a carrier with good bacterial counts after 4 weeks. In terms of bacterial survival, Bowen and Kennedy [1959] considered 40° C as critical to the survival of some rhizobia. When *R. japonicum* were applied with peat to the seed, Davidson and Reuszer [1978] recovered 0.1 to 1.7 percent of the original population when stored at only 30° C for 3 weeks. Kaul and Sekhon [1977] found that

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mulching lowered the soil temperature by 10° C. The results were early, more uniform nodulation and improved soybean yields.

Since the soil moisture is known to modify soil temperatures, these two factors are closely related in rhizobial survival. Diatloff [1970] stated that the dessication of nodule bacteria in seed inocula would be unlikely in soil moist enough to germinate seed. However, Diatloff [1967] reported that an absence of nodules was recorded during excessively wet or dry conditions. Worrall and Roughley [1967] reported that moisture stress and the method of inoculation greatly affected the number and distribution of infected root hairs and nodules of young seedlings of *Trifolium subterraneum*. A reduction of soil moisture potential from -0.36 to -3.6×10^5 Pa significantly decreased the number of infection threads and completely inhibited nodulation, although the number of rhizobia in the rhizosphere was unaffected.

Methods such as inoculant placement at depths below the seed have been investigated [Hely, Hutchings, and Zorin, 1976; Scudder, 1974; Wilson, 1975]. The reports indicate potential value in protecting the applied rhizobia from temperature and moisture stresses occurring in the seed zone.

This paper examines soybean nodulation under dry and irrigated field conditions. Evaluations are given of different inoculant types, rates, and inoculant placements.

MATERIALS AND METHODS

A single batch of *R. japonicum* strain 8-0 with a count of 1.6×10^9 cells/ml was utilized in the preparation of the following inoculants: peat powder for seed application (3.0×10^5 cells/seed), granular peat for soil application (7.2×10^6 cells/cm of row), and the liquid broth for soil application (7.2×10^6 cells/cm of row). Each inoculant type was utilized at the above base rate designated as 1X and a rate 10 times the base rate, designated as 10X. The liquid soil inoculant was placed in the furrow on the seed and also at 2.5, 5.0, and 7.5 cm below the seed at a rate of 75 ml/6m of row. Sucrose solution was used to adhere 3.1 g of peat powder/kg of seed. Granular inoculant was added on top of the seed in the furrow at the rate of 3.4 grams per 6 meters of row.

The experiment was located at the Isabela substation of the Agricultural Experiment Station, University of Puerto Rico on an Oxisol (Coto kaolinitic clay) which was free of *R. japonicum*. The Jupiter variety of soybeans was planted on March 7, 1979 (during the dry season in Puerto Rico). This allowed the establishment of all treatments in the field in both a dry soil (no water before and 7 days after planting, followed by irrigation to initiate seed germination and plant growth) and a moist soil (irrigation following planting and subsequently to maintain moist conditions). The plots had 4 rows that were 6 m long with 60 cm between the rows. The experiment was replicated 4 times in a randomized complete-block design.

Seven-day cycle soil-temperature recorders with probes at 2.5 and 10 cm were placed in both the dry and moist sections of the field to monitor the soil temperature.

Five plants per plot were evaluated at 32 and 98 days after planting for the number of taproot nodules, total number of nodules, and nodule dry weight per plant.

RESULTS AND DISCUSSION

The soil was dry at planting. Because there was no rain during the following 7 days, the dry state was successfully maintained in the dry section of the field for this period (Figure 1). The soil moisture was continually below the wilting point (2.5 percent). After 7 days, water was applied to the dry side to initiate seed germination. Without plant growth, rhizobial survival and nodulation could not be evaluated. The irrigated section received water after planting and at frequent intervals to maintain the soil moisture between the wilting point and field capacity (29.6 percent). The maximum soil temperatures at 2.5 cm in the dry plots were between 38° and 40° C, which was 3° to 8° C hotter than the maximum in the

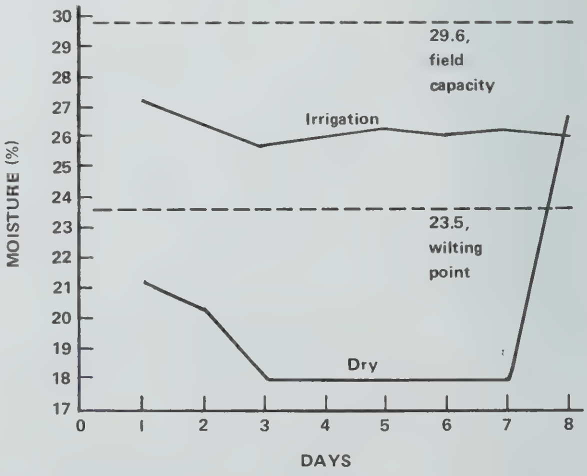

Figure 1. Percent of soil moisture during first week in dry and irrigated plots.

irrigated plots (Figure 2). The daily minimum temperature under both moisture regimes was below 26° C. Clouds during day 3 eliminated temperature differences between the two moisture conditions. Temperatures at 10 cm ranged between 21° and 27° C with no significant difference between the two moisture conditions.

By examining the number of taproot nodules per plant at day 32, we evaluated the ability of the inoculants to provide early and effective nodulation. Under dry conditions, only the granular soil inoculant at the 10X rate was better than the remaining treatments (Table 1). Under irrigation, this treatment was also superior as were the granular 1X rate and the liquid soil inoculant delivered in the furrow over the seed at the 10X rate. The superior performance of the granular inoculant is evident in comparing treatment totals (Table 1). Comparing the 1X and 10X rate totaled among treatments in dry and irrigated conditions (1.6 to 4.5 and 6.0 to 12.3, respectively) indicates more than twice as many taproot nodules were formed with the inoculants at the 10X rate. Evaluating moisture totals between the dry and irrigated plots (6.1 and 18.3, respectively, Table 1) indicates that 3 times more taproot nodules were formed under the moist conditions than under the dry conditions.

The total number of nodules per plant at day 32 (Table 2) follows a pattern similar to that of the tap nodules, with the granular 10X rate significantly better than all other treatments under both dry and irrigated conditions. The inoculant treatment totals (Table 2) also show the granular inoculant to be superior to both

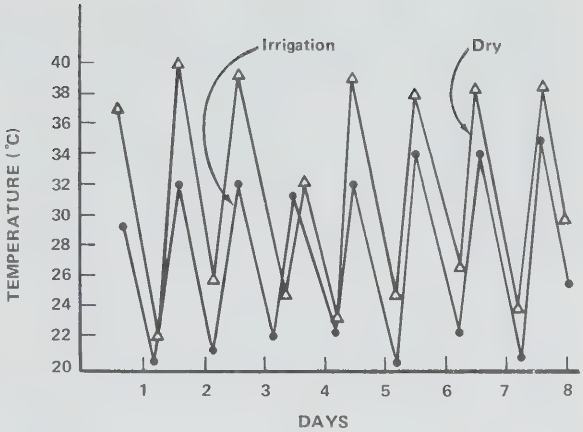

Figure 2. Soil temperature at 2.5 cm during the first week in dry and irrigated plots.

the liquid soil inoculant on the seed and at 2.5 cm below the seed, and better than the other inoculant types. The rate total under dry conditions (Table 2) indicates that the 10X rate is less than double the 1X rate; however, under irrigation, the rate total for 10X is double the 1X rate. As with tap nodules, an evaluation of moisture totals between dry and irrigation (30.1 and 99.7, respectively, Table 2) shows that 3 times more nodules were formed under the irrigated conditions than the nonirrigated ones.

The nodule dry weight per plant (Table 3) is very similar to the total number of nodules—with the granular treatment providing the most nodule weight, followed by liquid on the seed and liquid placed 2.5 cm below the seed. There is no difference in

Table 1. Number of Tap-Root Nodules at 32 Days: Effect of Soil Moisture, Inoculant Type, and Rate

Inoculant treatment	Dry† 1X†† rate	Dry† 10X††† rate	Irrigation† 1X†† rate	Irrigation† 10X††† rate	Treatment total
Control	0 b	...	0 c	...	0
Peat	0.1 b	0.3 b	0.9 c	1.4 c	2.7
Granular	0.9 b	2.5 a	3.3 b	5.3 a	12.0
Liquid on seed	0.3 b	0.8 b	0.6 c	3.1 b	4.8
Liquid 2.5 cm below seed	0.2 b	0.9 b	0.5 c	1.3 c	2.9
Liquid 5.0 cm below seed	0 b	0 b	0 c	0.9 c	0.9
Liquid 7.5 cm below seed	0.1 b	0 b	0.7 c	0.3 c	1.1
Rate total	1.6	4.5	6.0	12.3	
Moisture total	6.1		18.3**		

†Means followed by the same letter within dry treatment or within irrigation treatment are not significantly different at the 0.05 level using Duncan's Multiple Range Test. ††Base rate. †††Ten times the base rate.
**Significant difference at the 0.01 level between dry and irrigation treatments.

Table 2. Total Number of Nodules at 32 Days: Effect of Soil Moisture, Inoculant Type and Rate

Inoculant treatment	Dry† 1X†† rate	Dry† 10X††† rate	Irrigation† 1X†† rate	Irrigation† 10X††† rate	Treatment total
Control	0 b	...	0.2 d	...	0
Peat	0.2 b	0.8 b	2.1 d	4.8 d	7.9
Granular	4.1 b	11.3 a	16.6 b	33.1 a	65.1
Liquid on seed	2.4 b	2.1 b	6.0 cd	13.8 bc	24.3
Liquid 2.5 cm below seed	4.3 b	4.3 b	4.0 d	8.0 cd	20.6
Liquid 5.0 cm below seed	b	0.1 b	0.4 d	3.6 d	4.1
Liquid 7.5 cm below seed	0.3 b	0.2 b	2.7 d	4.4 d	7.6
Rate total	11.3	18.8	32.0	67.7	
Moisture total	30.1		99.7**		

†Means followed by the same letter within dry treatment or within irrigation treatment are not significantly different at the 0.05 level using Duncan's Multiple Range Test. ††Base rate. †††Ten times the base rate.
**Significant difference at the 0.01 level between dry and irrigation treatments.

nodule weight between the 1X and 10X rates under dry conditions; however, nodule weight under the 10X rate is more than double the 1X rate under irrigation. As with the number of tap nodules and the total number of nodules, the nodule dry weights (62.6 and 193.8 mg) under different moisture regimes showed more than 3 times the dry weight for nodules formed under the irrigated conditions than under dry ones.

Nodule parameters were evaluated at day 98 to determine whether nodulation trends would change with time. The treatment order at 98 days was similar to that at 32 days for the treatment totals of tap root nodules (Table 4), total number of nodules (Table 5), and nodule dry weight per plant (Table 6). The granular inoculant was consistently the best, with liquid on the seed and liquid at 2.5 cm overall better than the remaining treatments. Liquid at 5 and at 7.5 cm below the seed did not produce significant tap root nodules under either moisture condition because inoculant placed at these depths is below the infection zone for the tap root. However, those treatments did produce more than 25 total nodules under irrigation (Table 5), whereas less than 5 nodules were formed in the dry soil. This suggests that inoculum placed at these depths can survive outside of the rhizosphere under moist conditions but not under the dry regime.

The advantage of the 10X rate over the 1X rate between all nodule parameters was no longer significant at 98 days (Tables 4, 5, 6).

Table 3. Nodule Dry Weight per Plant in Milligrams at 32 days: Effect of Soil Moisture Inoculant Type, and Rate

Inoculant treatment	Dry† 1X†† rate	Dry† 10X††† rate	Irrigation† 1X†† rate	Irrigation† 10X††† rate	Treatment total
Control	0 c	...	0.7 d	...	0.7
Peat	0.7 bc	1.4 bc	5.2 cd	18.8 bc	26.1
Granular	10.5 abc	17.1 a	21.1 bc	47.7 a	96.4
Liquid on seed	5.6 bc	6.1 bc	16.7 bcd	28.0 b	56.4
Liquid 2.5 cm below seed	11.0 ab	7.3 abc	9.0 cd	14.4 bcd	41.7
Liquid 5.0 cm below seed	0 c	0.2 c	0.4 d	11.5 bcd	12.1
Liquid 7.5 cm below seed	2.3 bc	0.4 bc	8.6 cd	11.7 bcd	23.0
Rate total	30.1	32.5	61.7	132.1	
Moisture total	62.6		193.8**		

†Means followed by the same letter within dry treatment or within irrigation treatment are not significantly different at the 0.05 level using Duncan's Multiple Range Test. ††Base rate. †††Ten times the base rate.
**Significant difference at the 0.01 level between dry and irrigation treatments.

However, the effect of moisture is still indicated in that the total number of nodules and the nodule dry weight per plant were still 3 times larger under irrigation (956.1 nodules and 4,065.9 mg, respectively) compared to dry conditions (244.1 nodules and 1,214 mg, respectively). This increase under irrigation was the same as that observed at 32 days. However, the moisture total for tap root nodules under irrigation (43.6) became 6 times larger than under dry conditions (6.9). The reason is that the number of tap nodules under dry conditions did not increase between the sampling on day 32 and day 98, while the number of tap nodules more than doubled under irrigation.

In summary, the granular soil inoculant was superior under both dry and moist conditions. The liquid placed on the seed in the furrow and the liquid in the soil at 2.5 cm below the seed performed better than the remaining treatments. Seed with applied peat inoculant was found to be unsatisfactory under dry conditions and significantly less effective than granular under irrigated conditions. Liquid placed at 5 and at 7.5 cm below the seed was not effective in protecting the rhizobia from moisture and temperature stresses.

The increased or high rate of each applied inoculant provided a general, but not significant, increase in nodulation parameters at both sampling dates. Dry soil conditions for the first week provided a strong stress to rhizobia in all inoculant types and rates. The amount of nodulation

Table 4. Number of Tap Root Nodules at 98 Days: Effect of Soil Moisture, Inoculant Type, and Rate

Inoculant treatment	Dry[†] 1X[††] rate	Dry[†] 10X[†††] rate	Irrigation[†] 1X[††] rate	Irrigation[†] 10X[†††] rate	Treatment total
Control	0 b	...	0 d	...	0
Peat	0 b	0.1 b	3.2 bcd	3.2 bcd	6.5
Granular	0.7 b	2.9 a	7.6 ab	11.3 a	22.5
Liquid on seed	0.2 b	0.6 b	6.1 bc	5.9 bc	12.8
Liquid 2.5 cm below seed	1.5 ab	0.7 b	1.0 cd	1.5 cd	4.7
Liquid 5.0 cm below seed	0.2 b	0 b	2.4 bcd	0 d	2.6
Liquid 7.5 cm below seed	0 b	0 b	0.2 d	0.9 cd	1.1
Rate total	2.6	4.3	20.5	22.8	
Moisture total	6.9		43.6**		

[†]Means followed by the same letter within dry treatment or within irrigation treatment are not significantly different at the 0.05 level using Duncan's Multiple Range Test. [††]Base rate. [†††]Ten times the base rate.
**Significant difference at the 0.01 level between dry and irrigation treatments.

Table 5. Total Number of Nodules at 98 Days: Effect of Soil Moisture, Inoculant Type, and Rate

Inoculant treatment	Dry[†] 1X[††] rate	Dry[†] 10X[†††] rate	Irrigation[†] 1X[††] rate	Irrigation[†] 10X[†††] rate	Treatment total
Control	1.5 d	...	7.7 d	...	9.2
Peat	12.9 cd	2.6 cd	76.1 abcd	59.7 bcd	151.3
Granular	27.5 bc	63.5 a	96.3 abc	139.8 ab	327.1
Liquid on seed	22.8 bcd	29.3 bc	80.5 abcd	146.3 a	278.9
Liquid 2.5 cm below seed	46.3 ab	28.8 bc	73.4 abcd	76.4 abcd	224.9
Liquid 5.0 cm below seed	1.5 d	1.9 a	25.4 cd	75.2 abcd	104.0
Liquid 7.5 cm below seed	4.3 cd	1.2 d	50.4 cd	48.9 cd	104.8
Rate total	116.8	127.3	409.8	546.3	
Moisture total	244.1		956.1**		

[†]Means followed by the same letter within dry treatment or within irrigation treatment are not significantly different at the 0.05 level using Duncan's Multiple Range Test. [††]Base rate. [†††]Ten times the base rate.
**Significant difference at the 0.01 level between dry and irrigation treatments.

Table 6. Nodule Dry Weight in Milligrams per Plant at 98 Days: Effect of Soil Moisture, Inoculant Type, and Rate

Inoculation treatment	Dry† 1X†† rate	Dry† 10X††† rate	Irrigation† 1X†† rate	Irrigation† 10X††† rate	Treatment total
Control	21.9 d	....	49.4 e	.....	71.3
Peat	25.5 d	32.9 d	247.2 cd	307.7 bcd	613.3
Granular	170.9 b	258.7 a	432.5 abc	519.5 a	1381.6
Liquid on seed	73.2 cd	148.2 bc	383.4 abc	460.0 ab	1064.8
Liquid 2.5 cm below seed	218.5 ab	181.0 ab	381.0 abc	305.0 bcd	1085.5
Liquid 5.0 cm below seed	14.0 d	31.6 d	162.0 de	247.7 cd	455.3
Liquid 7.5 cm below seed	24.4 d	13.2 d	257.3 cd	313.2 bcd	608.1
Rate total	548.4	665.6	1912.8	2153.1	
Moisture total	1,214.0		4,065.9**		

†Means followed by the same letter within dry treatment or within irrigation treatment are not significantly different at the 0.05 level using Duncan's Multiple Range Test. ††Base rate. †††Ten times the base rate.
**Significant difference at the 0.01 level between dry and irrigation treatments.

under irrigation was at least 3 times greater than in the dry soil at both sampling dates. Irrigation eliminated moisture stress and reduced maximun temperatures.

This study indicates that to establish effective soybean nodulation in an *R. japonicum*-free soil in the semitropics, an inoculant of high quality is essential; also, maintaining the soil moisture above the wilting point during the first week is critical.

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Nodulation and Response to the Inoculation of Soybeans Under Egyptian Conditions

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ABSTRACT: The soils of Egypt are void of *R. japonicum* strains. Greenhouse and field studies have indicated the response of soybeans to inoculation, provided that certain measures are taken.

An inoculation rate of 28 x 10^6 bacteria per seed caused almost 100 percent nodulation. The peat moss carrier, which replaced Okadin (Nile silt soil), seems promising to ensure this rate. The current methods of propagating rhizobia, e.g., batch cultures, should be developed into submerged methods. Salinity reduced the growth of *R. japonicum* and the response to inoculation. Soybean seeds produce toxic substances for soybean rhizobia. These toxins disappear by soaking the soybean seeds for 4 hours.

The moisture and temperature stress prevailing in dry or wet soils after soybeans are planted may contribute to nodulation failure. The first irrigation is important for the viability of rhizobia. The use of thermotolerant rhizobia and granular inoculants may overcome such problems.

Certain fungicides may interfere with nodulation on soybeans, e.g., Phygon was inhibiting, Spergon was less toxic, and Orthocide at 0.3 percent was stimulating. Increased rates of Benlate (benomyl) or Vitavax captan tended to show harmful effects. The use of so-called "compatible fungicides" and granulated inoculants may avoid the harmful effects of fungicides.

SEVERAL STUDIES IN DIFFERENT LABORATORIES in Egypt were conducted to investigate the presence of *R. japonicum* in Egyptian soils, the response of soybeans to inoculation, as well as the effects of nitrogen fertilizers, salinity, and toxic materials, e.g., seed-coat diffusates and fungicides.

LABORATORY AND GREENHOUSE STUDIES

The soils of Egypt were found to be void of *R. japonicum* strains [Hamdi *et al.*, 1973; Abd El-Ghaffar, 1976]. The response of soybeans to inoculation was evaluated in different studies. The soybean varieties Hampton, Hill, and Lee were cultivated in pots in Nile silt. Single and composite strains of *R. japonicum* were applied. The varieties were grown together or separately and then combined before inoculation. The response to strain E-41 was significantly different from the control plants. Inoculation with mixed strains gave inconsistent results [Hamdi *et al.*, 1968].

In another study, the response of Clark soybeans to inoculation in saline, alkaline, calcareous, heavy clay, and sandy soils was evaluated [Abd El-Ghaffar,1976]. Various strains of *R. japonicum* produced marked differences in plants grown in various soils. Some strains were much more effective than others, e.g., strains 3417 and E-41 were more effective than E-38 and E-45. The response of nodulating and non-nodulating soybean varieties Chip and Clay to inoculation showed that the response to different strains of *R. japonicum* varied with different combinations (Table 1). Nodulating soybean isolines produced more dry matter and a higher nitrogen content than controls and non-nodulating isolines. Uninoculated control plants produced an average dry matter yield and nitrogen content quite similar to those from non-nodulating plants [El-Mallah, 1978].

The interaction between fertilizers and inoculation was studied by Ashour *et al.* [1969]. Inoculated and non-inoculated Hampton soybeans were cultivated in pots containing 40 kilograms of Nile silt and fertilized with 6 or 12 grams per pot of $CaNO_3$. Either inoculation or fertilization increased the dry matter weight and N content of the

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Table 1. Dry Matter and Nitrogen Content per Plant of Certain Soybean Isolines Inoculated with Six R. japonicum Isolates

R. japonicum isolate	Clay, non-nodulated: Dry weight (g)	Clay, non-nodulated: N content (mg)	Clay, nodulated: Dry weight (g)	Clay, nodulated: N content (mg)	Chip, non-nodulated: Dry weight (g)	Chip, non-nodulated: N content (mg)	Chip, nodulated: Dry weight (g)	Chip, nodulated: N content (mg)
Control	1.02	9.90	1.07	10.01	1.05	10.50	1.03	10.00
C_1	0.99	9.42	1.71	29.89	1.02	9.99	1.77	28.80
C_2	1.13	10.30	1.99	38.21	1.05	9.91	2.03	35.80
C_3	1.00	9.69	2.26	46.69	1.03	10.82	2.04	39.50
H_1	1.04	9.99	2.04	40.22	1.16	11.02	2.29	48.81
H_2	0.89	9.02	1.64	29.70	1.21	10.49	1.77	36.39
H_3	0.97	9.62	1.92	36.49	1.12	10.99	1.98	40.10

Source: El-Mallah, 1978.

soybean plants. Adding N to the inoculated plants increased the growth and the N content more than either inoculation or fertilizer alone. Inoculation increased the weight of pods and the number of seeds per plant (Table 2).

With respect to salinity, Alaa El-Din [1976] studied the susceptibility of different strains of *R. japonicum* E-38, E-41, E-45, 529, and N-2 to different concentrations of NaCl (0, 0.1, 0.2, 0.3, 0.5, 1, 2, 5, and 10 percent) in liquid media. The growth curves showed that the isolate N-2 (which was isolated from soybeans growing in saline soil) was the most tolerant to NaCl, while strain E-45 was the most susceptible.

Increasing the salt concentration in irrigation water led to a significant decrease in the weight of the plants, pods, and nodules as well as their enzymatic activities. The extent of this negative effect was much higher with strain E-45 than with the salt-tolerant N-2 strain.

In a different study, the effect of increasing levels of NaCl and Na_2SO_4 (0, 0.1, 0.2, 0.4, 0.8, and 1.5 percent) in sand culture using Davis soybeans inoculated with strain E-45 was studied [Abd El-Ghaffar, 1976]. The results (Table 3) showed that nodulation, dry weight, and N_2 fixation gradually decreased as the salinity increased. Soybean growth was totally inhibited at 0.8 percent or more of NaCl and at 1.5 percent Na_2SO_4. However, at 0.1 percent Na_2SO_4, growth stimulation was noticed.

The toxicity of soybean seeds to *R. japonicum* strains was studied [El-Mallah, 1978]. Seed diffusates of the four soybean isolines inhibited the growth of *R. japonicum* isolates to different degrees. Soaking the soybean seeds in water for 4 hours eliminated or prevented the toxic effects of the seed diffusate. Seed diffusates of non-nodulating isolines inhibited rhizobial growth more than the nodulating ones. The non-nodulating Clay isoline showed inhibited zones of 5 to 8 millimeters. The nodulating one showed zones of 2 to 4 millimeters. The Chip non-nodulating isoline caused inhibition zones of 6 to 7 millimeters, compared to ones of 1 to 2 millimeters for the nodulating isoline.

The sensitivity of *R. japonicum* strains to fungicides was determined [Afifi *et al.*, 1969]. TMTD, Thizoctole, Phygon, Ceresan, and Orthocide 75 at concentrations of 30, 0.3, 0.03, and 0.003 percent, respectively, caused different inhibition zones for five strains of *R. japonicum.* The diameter of the inhibition zones was proportional to the concentration of the fungicide, being the largest with the 3 percent concentration. The toxicity the levels 3 and 0.3 percent of all fungicides inhibited the five strains.

The effect of some of these fungicides on the symbiotic system of *R. japonicum*

Table 2. Effect of Inoculation and Nitrogen Fertilizer on the Yield of Hampton Soybeans

Calcium nitrate (g/40 kg pot)	Inoculated: No. of seeds	Inoculated: Weight (g/pot) Seeds	Inoculated: Weight (g/pot) Pods	Not inoculated: No. of seeds	Not inoculated: Weight (g/pot) Seeds	Not inoculated: Weight (g/pot) Pods
0	91	18.2	24.4	75	12.0	17.2
6	124	20.2	28.5	91	13.2	21.6
12	147	25.6	37.1	76	14.1	23.4

Source: Ashour *et al.*, 1969.

Table 3. Effect of Increasing Levels of Salts on N_2 Fixation of Davis Soybeans per 10 Plants

Salt concentration (%)	Na Cl treated No. of nodules	Na Cl treated Dry weight (g)	Na Cl treated Total N (mg)	Na_2SO_4 treated No. of nodules	Na_2SO_4 treated Dry weight (g)	Na_2SO_4 treated Total N (mg)
Control plants, not inoculated	0	5.64	82.5	0	5.64	82.5
0	626	11.03	284.6	626	11.03	284.6
0.1	442	4.25	235.0	615	10.99	304.4
0.2	241	5.19	117.9	188	6.22	117.4
0.4	110	4.63	90.5	107	5.10	94.3
0.8		No growth		9	3.61	63.9
1.5		No growth			No growth	

Source: Abd El-Ghaffar, 1976.

Table 4. Dry Matter Weight and Nitrogen Content of Inoculated Soybeans Treated with Fungicides

Fungicide	Weight (g/pot)	Total N (mg/pot)
Control	19.21	429.3
Spergon - 0.3%	12.30	383.0
Spergon - 3.0%	12.30	385.6
Phygon - 0.3%	9.11	242.1
Phygon - 3.0%	7.21	214.6
Orthocide - 0.3%	18.65	497.5
Orthocide - 3.0%	14.50	321.8

Source: Hamdi *et al.*, 1974.

Table 5. Effect of Benlate and Vitavax Captan Applied at Various Concentrations on Inoculated Soybean Seeds at 48 Days after Planting

Fungicide	No. of nodules per pot	Weight (g/pot)	N content (mg/pot)
Control[a]			
I	171	15.18	277.4
NI	...	13.50	209.6
Benlate			
I	154	13.37	246.8
NI	...	12.12	204.9
I	142	13.75	250.7
NI	...	14.11	229.2
I	155	13.94	245.6
NI	...	14.36	220.8
Vitavax captan			
I	134	14.60	281.8
NI	...	14.40	234.8
I	128	12.91	242.5
NI	...	13.73	214.2
I	131	13.07	225.4
NI	...	13.26	199.7

[a]I=inoculated; NI=not inoculated.
Source: Loutfi *et al.* (1979), unpublished.

and soybeans was studied [Hamdi *et al.*, 1974]. Phygon and Orthocide 75 were used at 3 and 0.3 percent. Phygon (Table 4) was very inhibiting. Spergon had less of an effect. Orthocide at 0.3 percent was stimulating, but was harmful at 3 percent.

A different study [Loutfi *et al.*, 1979, unpublished data] showed that Benlate and Vitavax plus captan at 1, 2, and 39 per kilogram of seeds had a depressing effect on nodule dry weight and N_2 fixation in inoculated plants at 48 days (Table 5). The dry matter weight of the plants, yield of seeds, and total N content of the inoculated plants at harvest again showed a similar trend, i.e., with the increase of either Benlate or Vitavax plus captan a reduction occurred in these components (Table 6). This reduction, however, was not significant. One gram of

Table 6. Dry Matter Weight of Plants and Seeds at Harvest of Soybeans Grown from Seeds Inoculated and Treated with Benlate and Vitavax Captan

Fungicide	Weight (g/pot) Plants	Weight (g/pot) Seeds	Total N (mg/pot)
Control[a]			
I	17.29	5.36	386
NI	15.52	2.98	237
Benlate[a]			
I	17.38	5.44	539
NI	16.59	3.50	327
I	18.24	4.54	321
NI	17.63	3.46	278
I	17.45	5.03	361
NI	16.52	3.85	213
Vitavax Captan[a]			
I	17.89	5.40	478
NI	16.15	3.63	323
I	18.12	5.09	398
NI	15.25	3.49	212
I	16.01	5.19	377
NI	15.98	3.40	244

[a]I=inoculated; NI=not inoculated.
Source: Loutfi *et al.* (1979), unpublished.

either fungicide per kilogram of seed tended to enhance or show no significant effect. Non-inoculated plants were not significantly affected by the fungicidal treatments on any of the test dates, i.e., at 48 days or when harvested at 110 days.

INOCULANT PRODUCTION

Inoculants for soybeans and other legumes are prepared by the Department of Microbiology at the Agriculture Research Center in Dokki. The inoculant Okadin was developed in 1958 [Loutfi and Fahmi, 1958]. The rhizobial cultures are grown in batches, in flasks of 1 to 2 liters in agitated cultures. A carrier of Nile silt soil enriched with phosphate, sugar, gelatin, and charcoal is distributed in tin cans and sterilized. When broth cultures attain enough growth, e.g., 10^9/ml, the cultures are distributed into sterile carriers to give 70 percent of the water-holding capacity. The inoculants are then ready for use.

In 1978, an inoculant was developed using Jiffy 7 disks which are made from peat moss impregnated with certain minerals [Fouda *et al.*, 1979]. The preparation of the broth culture was modified as follows. Rhizobial cultures are first grown on agar slopes in bottles. After enough growth, they are washed into broth and agitated for 48 to 96 hours. That broth is then transferred into steamed peat moss disks distributed in plastic cans.

The units of inoculants produced for soybean reached 10,000 in 1979. This was enough to inoculate seeds cultivated in 10,000 feddans[1], which represents about 10 percent of the total area cultivated with soybeans (98,000 feddans in 1979).

FIELD STUDIES

The field studies were relatively limited. As mentioned earlier, Egyptian soils are free of *R. japonicum*. Therefore, the establishment, proliferation, and response to inoculation were important objectives for field studies. However, the field studies were all done by the Department of Microbiology of the Agriculture Research Center.

The inoculation rates of *R. japonicum* cells per seed were evaluated under greenhouse and field conditions [Hamdi *et al.*, 1973]. Seeds of Clark soybeans were inoculated at the rate of 28×10^6, 28×10^5, and 28×10^4 cells per seed. Inoculated seeds were planted in field plots or in pots containing the same silty loam soil and kept under greenhouse conditions at the Giza Research Station.

Nodulation was abundant within 3 weeks. The pot experiments contained seeds that had been inoculated with 28×10^6 cells per seed. No nodules were observed after 3 weeks under field conditions or in plants in the pots receiving 28×10^4 cells per seed. After 57 days in the field, nodulation was between 87 to 92 percent when rhizobia were inoculated at the rate of 28×10^6 cells per seed. Nodulation dropped to 47 percent with an inoculation of 28×10^4 cells per seed. Nodulation of 100 percent was seen in plants receiving 28×10^6 cells per seed in pot cultures, decreasing to 50 percent for plants inoculated with 28×10^4 cells per seed. After 102 days, the nodulation frequency, fresh weight of the nodules, and dry weight of the stems and pods were determined; these weights increased with the number of rhizobia in the inoculant (Table 7).

In 1977, the inoculant Nitragin was imported by the Permanent Council of Soybeans in Egypt. The number of rhizobia in this inoculant was 100×10^6 cells per gram. The inoculant was used with gum arabic at the rate of 120 g of inoculant per 30 to 40 kilograms of seed. A total of 1,000 feddans was inoculated with Nitragin and 1,150 feddans with local inoculum in the northern area (Noubaria and Tahrir) and in Gharbia, Behera Menofya, Dokahlya, Menia, Beny Seweif, and Sharkia.

Nodulation was successful in some areas, but failed in others. The reports showed a total of 40 to 50 nodules with 15 to 20 nodules per plant in Beny Seweif and 6 to 10 nodules per plant in Behira. In many areas, no nodules were produced.

In 1978, the inoculant Legume-aid was imported from the United States by the Permanent Council for Soybeans in Egypt. The inoculant was used at the rate of 200 g per 30 to 40 kilograms of seed. Seeds for about 40,000 feddans were inoculated.

The results showed that 2 to 15 nodules were formed per plant in most locations. In two areas, the average number of nodules was 50 to 100 nodules per plant. At many locations there was no nodulation.

Peat moss inoculant was compared with the Legume-aid (from the USA), Okadin (Nile silt), and a mixture of soil and charcoal at a 1:3 ratio. The results showed a good response to all three. However, Legume-aid and the mixture of soil and charcoal produced fewer nodules than Okadin or the peat moss inoculant. Similarly, yield responses showed significant increases with the Okadin and peat moss inoculants.

In 1979, the developed inoculant from peat moss disks was used to inoculate 10,000

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[1] *1.04 feddans equal 1 acre.*

Table 7. Response of Clark Soybeans to the Number of R. japonicum Cells per Seed Used as Inoculant at 102 Days after Planting under Field Conditions

R. japonicum (cells/seed)	Plant dry weight (g/plant)	Plants nodulated (%)	Nodule fresh weight (g/plant)	Nodules (no./plant)
Uninoculated	9.8 $\pm$ 1.0	0	0	33.0 $\pm$ 2.63
28 x 10^4	12.1 $\pm$ 1.2	93.3	1.30	46.5 $\pm$ 6.41
28 x 10^5	10.5 $\pm$ 1.9	81.0	0.70	28.0 $\pm$ 5.90
28 x 10^6	9.7 $\pm$ 1.4	57.0	0.30	31.1 $\pm$ 9.10

Source: Hamdi *et al.*, 1973.

feddans. An examination 5 weeks after planting showed that nodulation ranging from 150 to 250 nodules per plant (an excess) in some governorates to 25 to 50 nodules per plant (moderate) in others. The nodulation rate in other governorates was low (10 to 20 per plant). On the other hand, nodulation failure was observed in many areas.

CONCLUSIONS AND REMARKS

In general, nodulation failure of soybeans could be due to (1) not enough rhizobia in the inoculant; (2) the death of rhizobia on the seeds caused by high temperature, drought, seed-coat diffusates, or some combination; (3) an inadequate method of inoculation; and (4) seed treatment with fungicides toxic to *R. japonicum*.

Several findings point to the importance of the inoculation rate. As the number of rhizobia per seed increases, so do the chances of good nodulation. An inoculum of 28 x 10^6 cells per seed may cause almost 100 percent nodulation. Achieving a large quantity of inoculant requires improved methods of cell propagation and carriers. In Egypt, rhizobia for inoculants are propagated at a laboratory scale, i.e., batches of 1 to 2 liters in agitated cultures. Another method was developed. The rhizobia are grown first on an agar surface and then washed into the medium, which is then agitated. These methods are sufficient for low quantities of inoculants. The submerged method of cell production is conventional and should be adopted. The Nile silt carrier is currently replaced by the peat moss disks. This was tested and found acceptable, and it will support high numbers of rhizobia.

Soybeans are planted in Egypt either in dry or wet soils. The first irrigation after planting is very important. In some instances, the irrigation water does not reach the field at the proper time, seriously affecting the survival of rhizobia on soybean seeds. Efforts should be made to avoid letting the soil dry out, which is usually accompanied by high temperatures in April or early May in Egypt. Granular inoculants should be tested. The selection of thermotolerant and effective strains of *R. japonicum* should be studied. What constitutes detrimental moisture for nodulation under field conditions should be determined.

The use of fungicides with inoculated seeds may interfere with nodulation. The selection of so called "compatible fungicides" with no toxicity to rhizobia should be studied. Again, granulated inoculants may help.

Another factor that may contribute to the lack of nodulation on soybeans is the failure to use an inoculant. Farmers have much respect for nitrogen fertilizers but not for inoculants. A wide extension program should be launched to teach farmers and the extension staff about the importance and proper use of the inoculants.

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Seed-Borne Pathogens of Irrigated Soybeans

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ABSTRACT: Environmental conditions—particularly high temperature and moisture—during seed development, at harvest time, and during storage play an important role in the establishment of microorganisms in soybean seeds. Most of the seed-borne fungal, bacterial, and viral pathogens of soybeans are located inside the seed. These disease agents can reduce seed quality. Pathogens carried in seeds are a source of primary inoculum for the next season's crop and help distribute the pathogen into areas where it may not be established. Individual seeds in each seed population may vary by the type and number of microorganisms carried.

Although loss to diseases generally is presumed to be less in irrigated soybeans, certain pathogens may be just as damaging as under nonirrigated cultivation. Some of the diseases reported in soybeans under irrigation are: charcoal rot, stem and root rots, pod and stem blight, downy mildew, purple seed stain, and at least three viruses. All diseases that occur in irrigated soybeans are seed-borne ones, except rust.

Thus, measures to assure that the seed planted is relatively free of seed-borne pathogens is one means of controlling diseases. However, when pathogens such as *Macrophomina phaseolina* (charcoal rot) are soil-borne and have a wide host range, using seeds absolutely free of the pathogen will not assure disease control.

The control methods for seed-borne pathogens of soybeans are nonchemical and chemical. The nonchemical methods include proper harvesting and storage, handling to avoid injuries, and using high-quality seeds that are relatively free of seed-borne microorganisms. The chemical methods include using fungicide sprays as the soybeans approach maturity and making seed dressings with conventional application methods, or by infusing seeds with systemic fungicide and/or antibiotics using a solvent system.

A careful diagnosis of problems with seed quality, particularly when relating them to seed-borne microorganisms, is necessary for proper control.

EVERY POPULATION OF SOYBEAN SEEDS can carry a wide variety of microorganisms and viruses. Seed lots can be contaminated with soil peds that harbor nematode cysts, spores of fungi and bacteria, infected plant-debris particles, sclerotia of various fungi and/or smut galls [Schiller and Sinclair, 1979]. Many of the storage fungi and bacteria are carried on the outside of the soybean seed, such as species of *Alternaria*, *Aspergillus*, *Penicillium*, and *Rhizopus* as well as many others [Mengistu and Sinclair, 1979; Sinclair and Shurtleff, 1976]. Most of the fungal and bacterial pathogens that are seed-borne in soybeans are carried internally, either in the seed coat or in embryo tissues [Rodriguez-Marcano and Sinclair, 1978; Sinclair, 1978]. These disease agents can reduce seed quality. Pathogens carried on or in seeds are a source of primary inoculum for the next season's crop and help distribute the pathogen into areas where it may not be established. Individual seeds in each seed population may vary in terms of the type and number of microorganisms they carry. The lack of high-quality seed

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produced under irrigated conditions was stressed by several speakers at the conference. (See the papers by P.F. Knowles and H.H. Hartwig.)

Environmental conditions during seed development, at harvest, and during storage play an important role in the establishment of microorganisms in soybean seeds. Insect populations and their activity as well as environmental conditions influence the spread of most of the viruses that infect soybeans. Under irrigation, particularly row irrigation, there are fewer types and lower quantities of seed-borne microorganisms than with seeds harvested from plants grown under rainfall or under overhead irrigation. However, the approaches to the control of seed-borne pathogens in irrigated soybeans are not different from those taken in regions of high moisture from rainfall.

LITERATURE REVIEW

Several general references and articles deal with seed-borne pathogens of soybeans [Sinclair and Shurtleff, 1976]. There are no specific or general references dealing with either diseases of irrigated soybeans or seed-borne pathogens of irrigated soybeans.

In a review of solicited reports on "World Soybeans Losses Caused by Disease" by R.E. Ford [University of Illinois at Urbana-Champaign, unpublished], the seed-borne pathogens listed from countries where soybean production is predominantly under irrigated conditions were: *Cercospora kikuchii* (purple seed stain); *Macrophomina phaseolina* (charcoal rot); *Peronospora manshurica* (downy mildew), *Phomopsis* sp. (pod and stem blight and seed decay); *Rhizoctonia solani* (damping-off and seed decay); and *Sclerotinia sclerotiorum* (damping-off). Ford lists several virus diseases in his review, including soybean mosaic and bud blight, as occurring in soybean fields.

In certain invitational papers and country reports presented at this conference and contained in the proceedings, reference is made to specific pathogens that are knwon to be seed-borne ones. In the paper by A.A.A. Ibrahim, A.M. Nassib, and M.H. El-Sherbeeny [1979], the following species of fungi were listed as attacking seeds and seedlings of soybeans under field conditions in Egypt: *Fusarium*, *Macrophomina*, *Pythium*, and *Rhizoctonia*. In the paper by M.N. Shatla, A.M. Basiony, and F. Salim [1979], the authors listed species of *Fusarium* and *Sclerotium rolfsii* as important soil-borne pathogens of soybeans. All of these fungi have been reported as seed-borne in soybeans [Sinclair and Shurtleff, 1976]. S.A. Mohamed [1979] lists 23 fungi isolated from surface-disinfected soybean seeds grown in Egypt in 1976 and 1977.

A. Khair [1979], reporting on soybean production in Bangladesh at this conference, listed the seed-borne pathogens *Colletotrichum dematium* var. *truncata* (anthracnose) and *Xanthomonas campestris (X. phaseoli* var. *sojensis)* (bacterial pustule) as occurring in his country. The bacterial pustule organism and *C. kikuchii* were reported in Sri Lanka [H. Gamage, 1979], also at this conference. Both are seed-borne pathogens. Bacterial pustule was stated as the most-important disease of soybeans in the Sudan in another report given at this conference [O.A.A. Ageeb and F.M. Khalifa, 1979].

In 1974, the soybean cultivars Amsoy 71, Beeson, Wayne, Williams, and Wells were grown in small field plots near the University of California at Davis by D.H. Hall. Frequent inspections for diseases were conducted, but no diseases were found. The California-grown seed was assayed for seed-borne fungi and bacteria, and germination

Table 1. Germination and Assays of Soybean Seeds, Five Cultivars Produced Under Irrigated Conditions near Davis, California, 1974

	Mean percentage[a]							
	Hard seed	Germination (°C)				Total fungi	*Bacillus subtilis*	
Cultivar[b]	coat	25	30	35	40	at 25°C	35°C	40°C
Amsoy 71	8	79	87	87	78	>1	>1	5
Amsoy 71-C	31	64	73	79	60	0	>1	>1
Beeson	50	39	43	53	32	0	4	4
Wayne	31	64	67	69	26	0	>1	5
Wells	21	69	77	74	2	>1	0	>1
Williams	>1	99	95	85	3	>1	>1	>1

[a]Based on 8 replications of 25 seeds per replicate.

[b]Seeds of all cultivars were Illinois Certified seed produced in 1973, except Amsoy 71-C which was produced in California in 1973.

Source: Data compiled by J.B. Sinclair.

Table 2. *The Effect of Seed Source on Soybean Plants and Yields in Illinois, 1975*

Cultivar	No. of plants harvested per 20 feet of row[b]	Plant height[b] (cm)	Yield[b] (kg/ha)
CALIFORNIA-GROWN SEEDS			
Amsoy 71	160	132	2,755
Amsoy 71[c]	153	133	2,957
Beeson	155	120	3,091
Wayne	150	123	3,226
Wells	179	116	3,158
Williams	145	131	3,360
ILLINOIS-GROWN SEEDS			
Amsoy 71	122	134	2,554
Beeson	168	110	2,822
Wayne	124	124	2,285
Wells	188	117	2,957
Williams	171	126	2,957

[a]California-grown seeds were from plants produced under irrigation in 1973 from Illinois Certified seed lots; Illinois-grown seeds were produced in 1973. Amsoy 71-C came from plants grown in California for 2 successive seasons under irrigation.
[b]Averages of 4 replicates.

Source: Data compiled by D.K. Whigham.

tests were conducted at various temperatures [J.B. Sinclair, unpublished]. The germination percentage varied with the cultivar and temperatures (Table 1). These differences were due in part to a "hard seed coat" condition. The most-significant observation was that the seed had a very low percentage of seed-borne microorganisms; however, *Bacillus subtilis* was isolated from all seed lots. *Bacillus subtilis* has been associated with seed lots from all over the world and causes a seed decay under certain conditions [Schiller *et al.*, 1977; Tenne *et al.*, 1977].

Samples of the California-produced seed were included in a variety trial conducted by D.H. Whigham at the University of Illinois (unpublished). There were some variations in plant height and the number of plants harvested, but all cultivars from seed produced in California yielded better than those from Illinois-grown seeds (Table 2).

Soybean mosaic has been observed in irrigated soybeans all over the world (personal communications), but is not considered as having an effect on yields. However, plants infected with soybean mosaic virus can give rise to blemished seeds, with a discoloration referred to as "hilum bleeding" [Sinclair and Shurtleff, 1976].

As this information strongly suggests, soybean seeds grown under irrigation cannot be guaranteed to be free of all seed-borne pathogens.

CURRENT RESEARCH AND DEVELOPMENTS

Little work is being done on the seed-borne aspect of soybean pathogens in irrigated soybeans. Research workers depend on the information derived from studies on soybeans grown under rainfall conditions. A master's thesis was completed recently in Egypt [Mohamed, 1979] in which the author reported 23 fungal genera and species isolated from soybean seeds grown in 3 locations in 1976 and 1977. The most common fungi were: *Alternaria alternata*, *Aspergillus* sp., and *Fusarium* species. Mohamed [1979] reported that spraying field plants with zinc, manganese, and copper fungicides reduced the average count of fungi associated with seeds. The most-effective compound for seed dressing was captan, which was more effective on poor-quality seeds (those with a high amount of seed-borne fungi) than on good-quality seeds.

A number of soybean diseases occur each year under irrigated conditions. For the present, we must assume that these pathogens are carried from season to season, in part, in the seeds. Evidently, under some conditions the pathogens are able to establish themselves on the host the next season and reproduce, infecting the seeds of that crop. There are no published studies, as far as the author knows, on the epidemiology of soybean pathogens in irrigated soybeans.

CONSTRAINTS ON EFFICIENT PRODUCTION

A consistent source of high-quality seeds for planting that are free of seed-borne microorganisms and viruses is one of the constraints on the efficient production of irrigated soybeans. Certain seed-borne microorganisms and viruses can reduce seed

quality and yields in temperate regions under rainfall conditions, but there are few comprehensive studies on the nature of the seed-borne microorganisms and viruses found under irrigated conditions. Studies need to be made on the differences between and epidemiology of seed-borne fungi, bacteria, and viruses of soybean seeds grown under furrow and overhead irrigation. Disease losses will be difficult to measure since a number of agronomic and engineering problems are associated with irrigated soybeans that need to be solved for maximum production.

Enough information is available to suggest that efforts need to be made at local, regional, and international levels to identify the microorganisms and viruses associated with irrigated soybeans and to develop a backlog of information on the losses due to these pathogens; also, to determine the economic thresholds of these pathogens. It has been suggested that producing soybean seeds under irrigation will provide a source of "pathogen-free" seeds for sowing in rainfall areas. The available information makes us doubt that contention. Also, when pathogens such as *M. phaseolina* (charcoal rot) are soil-borne, using pathogen-free seeds will not assure disease control.

Clearly, research efforts must be made to fully determine the occurrence of seed-borne pathogens of soybeans grown under irrigated conditions.

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Insect Resistance in Soybeans

E.E. HARTWIG

ABSTRACT: Resistance to foliar-feeding insects has been identified within the germplasm collection. Three strains—PI 171451, PI 227687, and PI 229358—have a high level of resistance to several foliar-feeding insects. This resistance is demonstrated by less feeding and a slower growth rate and by a higher mortality rate of the larvae. In our breeding program, we screened against the soybean looper [*Pseudoplusia includens* (Walker)] and later screened those selections against other foliar-feeding insects. No insect-resistant variety has been released, but progress is being made toward incorporating genes for resistance to foliar-feeding insects into types having good productivity along with resistance to major disease and nematode problems.

ALL SOYBEAN VARIETIES GROWN in the United States have upright pubescence. Glabrous and sparse oppressed pubescent types are presented in the germplasm collection, but these usually are severely damaged by the potato leafhopper *Empoasca fabae* (Harris) in most areas of the United States where soybeans are grown. Poos and Smith [1931] showed that more leafhopper nymphs hatched on glabrous and oppressed pubescent types than on those having upright pubescence.

Differential feeding by various foliar-feeding insects has been observed when soybean varieties were grown in an area. However, only recently has attention been given to incorporating a higher level of resistance to foliar-feeding insects into productive soybean varieties.

EXPERIMENTS AND RESULTS

In 1968, seed was furnished for making a field planting of approximately 600 varieties and germplasm strains of Maturity Groups VII, VIII, IX, and X at the Edisto Experiment Station in Blackville, South Carolina. Plantings had been made earlier to build up a heavy population of the Mexican bean beetle *Epilachna varivestis* Mulsant. Van Duyn, Turnipseed, and Maxwell [1971] reported differences in the degree of injury to various soybean strains. For further studies, they selected 18 strains showing the least damage and additional strains showing heavy feeding. These studies revealed that PI 171451, PI 227687, and PI 229358 definitely were the strains least preferred by the Mexican bean beetle. Van Duyn, Turnipseed, and Maxwell [1972] conducted additional studies in which Mexican bean beetles were forced to feed on PI 171451, PI 227687, and PI 229358. They found reduced longevity and fecundity in the adults and weight loss and high mortality in the larvae. On a susceptible soybean, for example, the average life of the females was 22.6 days and the mean number of eggs per female was 140. On PI 229358, the average life for females was 11.9 days. The mean number of eggs was 4.8. A high percentage of the larvae feeding on the resistant genotypes showed a heavy dropoff rate.

After observing the differences in feeding by Mexican bean beetles in the 1968 plantings in South Carolina, the 20 lines showing the least feeding were planted at Stoneville in order to increase seed stocks. Late in the season, there was a heavy infestation of the soybean looper [*Pseudoplusia includens* (Walker)]. The three strains (PI 171451, PI 227687, and PI 229358) clearly showed less feeding than the others.

Clark *et al.* [1972] reported results from a caged feeding trial using the same 20 soybean selections along with a few of the common varieties and exposing them to the bean leaf beetle [*Cerotoma trifurcata*

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(Forster)]. Strains PI 2278687 and PI 229358 showed the least feeding. PI 171451 also rated low. Studies with the striped blister beetle [*Epicauta vittata* (Fabricius)] showed PI 229358 and PI 171451 had less feeding than commercial varieties. Studies with the cotton boll worm [*Heliothis zea* (Boddie)] showed PI 227687 to have the greatest egg deposition but the least larval development.

These results demonstrated that soybean genotypes do have distinct differences in terms of their attractiveness for feeding by foliar-feeding insects; also, that there were differences in the rate of insect development when several unrelated insects fed on different soybean genotypes. The three soybean strains showing the highest level of resistance to foliar-feeding insects were all poor agronomic types. Thus, it was necessary to try to transfer the genes for resistance to productive, agronomically desirable types of soybeans. Preliminary results suggest that three major recessive genes may be involved in conferring the multiple-type resistance.

At Stoneville, the soybean looper is being used for primary screening. Moths are reared in the laboratory and released in the field cages as they are ready to mate and lay eggs. The cages are approximately 20 by 30 meters. Resistant plants or rows can be readily identified. Lines selected for resistance to looper feeding are then screened against Mexican bean beetles feeding in field plantings at Blackville, South Carolina. Screening against other insects is done in the greenhouse.

Advanced lines selected in a modified backcrossing program approach strain PI 229358 in their level of resistance. Several of the better lines have good agronomic qualities, but have averaged approximately 10 percent lower seed yields in the absence of insect feeding than the better varieties now in production.

Preliminary observations suggest that the type of resistance being developed may give protection against the cotton leaf worm [*Spodoptera littoralis* (Boisbuval)]. Cooperative tests are planned to measure the degree of protection that might be expected. Good protection from the beet armyworm [*Spodoptera exigua* (Hubner)] has been observed.

The survival and growth rates following placement of 66 first-instar larvae on 22 plants in greenhouse studies are shown in Table 1.

While the exact manner has not been established for the inheritance of resistance to feeding, it appears that resistance is recessive. This permits the use of resistant F_2 plants as parents in a modified backcrossing program. Attempts are being made to add resistance to foliar-feeding insects as another protective characteristic in a productive soybean variety that is resistant to major disease and nematode problems. Breeding material in the fourth and fifth cycles of breeding is now being evaluated. It is expected to be highly productive and to carry multiple pest resistance.

Studies have demonstrated that soybeans can tolerate as much as 40 percent defoliation with very little reduction in seed yield. With the present level of resistance along with natural predators and diseases, damage from leaf-feeding insects in soybeans can be greatly minimized. The larvae that develop more slowly should suffer more injury from predators and diseases than other larvae.

Another insect that causes problems in some areas of the southern United States is the southern green stink bug [*Nezara viridula* (Linnaeus)]. The stink bug feeds on the young pod by piercing. Stink bugs frequently carry a yeast fungus [*Nematospora coryli* (Peglion)] on their mouth parts. Infecting young seed with the fungus can cause the seed not to develop. The yeast fungus can also

Table 1. Survival and Development of Foliar-Feeding Larvae on Soybean Strains

Soybean strain	Velvetbean caterpillar No.[a]	Velvetbean caterpillar Wt. (mg)	Soybean looper No.[a]	Soybean looper Wt. (mg)	H. zea No.[a]	H. zea Wt. (mg)	H. virescus No.[a]	H. virescus Wt. (mg)
Davis	50	146	44	207	44	68	56	74.5
D75-10169	31	61	48	103	15	57	38	27.6
PI 229358	33	53	30	128	14	53	33	18.4
PI 227687	20	63	44	110	18	33	30	17.9

[a]Number surviving from 66 first-instar larvae.

cause damage to older seed. Resistance to the yeast fungus has been identified, and by incorporating this resistance into a productive variety, the yield reduction from stink bug feeding can be greatly minimized.

The two species of *Heliothis (H. zea* and *H. virescus)* feed on the developing pod. Segregating lines have been evaluated in the greenhouse in the seedling stage for rate of larval development. The first two or three stages of larval development seem to be on leaf material. Thus, selection in the early stages of plant development may be an effective way of identifying types that will be resistant to pod-feeding.

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Weed Control in Irrigated Soybeans

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ABSTRACT: Effective programs for weed control in irrigated soybeans involve a combination of techniques including cultural and chemical methods. In the Western United States, most of the soybeans grown under irrigation are planted as a double crop after the harvest of a winter cereal (usually wheat or barley). The major factor that makes approaches to weed control in this area different from the rain-fed Midwest soybean belt is the absolute dependency on irrigation to supply the plant's water requirements. Most of the herbicides used are applied preplant and usually incorporated to a depth of 2.5 to 10 centimeters, depending on the compound. Most soybean fields are surface-irrigated (flood or furrow). Since rainfall is not available to leach the herbicides, they must be preplant-incorporated for maximum control. The primary herbicides used commercially to suppress weeds in soybean fields are trifluralin, alachlor, chloropropham, and vernolate. Depending on the weeds anticipated, cultural practices used, and the succeeding crops (presistence problems), these preplant-incorporated herbicides have been used effectively alone and in combination on irrigated soybeans. In general, herbicides applied post-emergence (such as bentazon) have not been very effective.

EFFECTIVE WEED-CONTROL PROGRAMS in irrigated soybeans involve a combination of techniques, including cultural and chemical methods. In the western United States, most of the soybeans grown under irrigation are planted as a double crop after the harvest of winter cereals (mostly wheat or barley). The comments that follow reflect research and experiences by growers over the last 10 years in California's San Joaquin Valley. The major factor that makes approaches to weed control in this area different from the soybean belt of the Midwest is that the plant's water requirements must be supplied entirely by irrigation.

Most growers who double crop after the harvest of a winter grain follow the routine of disking the stubble 2 to 4 times, then irrigating the fields before planting. Such irrigation not only provides moisture for the germinating soybean seeds and for crop growth, but also moisture for weed seeds which germinate and are usually disked under during the preplant land preparation. Some growers burn the cereal straw and stubble to ease the problems of disking-in the residue. This is especially helpful to the smaller grower who does not have the large equipment required to adequately incorporate the residue from a cereal crop of 6,000 to 7,000 kilograms per hectare. Burning of the residue and using preirrigation are the main tools employed by growers to reduce volunteer populations of cereal grains in soybean fields. Because most growers are using narrow-row spacing (10 to 50 cm) and high plant populations, mechanical tillage for weed control once the crop is planted is minimal. Herbicides are perhaps the most important weed-control tool utilized in irrigated soybeans.

Most of the herbicides used in the San Joaquin Valley are applied preplant and are usually incorporated to a depth of 2.5 to 10 cm, depending on the chemical. In the San Joaquin Valley, most soybean fields are surface-irrigated (flood or furrow). Since rainfall or sprinklers are generally not available to leach the herbicides into the soil where the weed seeds are, the herbicides MUST be incorporated for maximum effectiveness.

Knowing what weeds are present in a grower's field is perhaps the key to successful weed control in such soybean fields.

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Table 1. Weed Control in Irrigated Soybeans, Showing the Relative Effectiveness of Various Herbicides and Incorporations (Data: J. Hill and W.D. McClellan)

Herbicide	Barnyard-grass	Lambsquarter, pigweed	Volunteer cereals	Nightshade, nutsedge	Incorporation depth (cm)
trifluralin (also other dinitroaniline herbicides)	+++[a]	+++	+	--	4 to 6
vernolate[b]	+++	+	+++	++	7 to 10
alachlor	+++	+	+	+++	4 to 6
chloropropham	--	--	+++	--	4 to 6
bentazon[c]	--	++	--	+	Postemergence

[a]Ratings: No control (--), partial control (+); weeds controlled (+++). [b]Some soybean injury in the form of delayed emergence, stunting, and leaf crinkling may occur when using vernolate. [c]Bentazon has performed eradically in the San Joaquin Valley and is not preferred.

Growers using surface-supplied water from the canals must also be aware that weed seeds are continually transported to crop fields from other areas. In the San Joaquin Valley, the major weeds are barnyard-grass (*Echinochloa* sp.), lambsquarter (*Chenopodium* sp.), pigweed (*Amaranthus* sp.), volunteer cereals, nightshade (*Solanum* sp.), and nutsedge (*Cyperus* sp.). Johnsongrass (*Sorghum halepense*) also presents major difficulties in several areas, and soybeans are not recommended where heavy infestations of this perennial weed are present.

The primary herbicides used commercially to suppress weed pressures in soybeans are trifluralin, alachlor, chloropropham, and vernolate. Table 1 summarizes the effectiveness of these herbicides against the major weeds. Some soybean injury in the form of delayed emergence, stunting, and leaf crinkling may occur when using vernolate. The symptoms usually disappear 2 to 3 weeks after planting. Bentazon has performed eradically in the San Joaquin Valley and is not preferred.

Depending on the seeds anticipated, cultural practices used, and the succeeding crops (persistence problems), these preplant-incorporated herbicides have been used effectively alone and in combinations in irrigated soybeans. In general, herbicides applied postemergence (such as bentazon) have not been very effective.

To summarize, effective weed control in irrigated soybeans depends on: (1) knowing what weeds are present in the field; (2) utilizing cultural practices effectively, such as a preplant irrigation and mechanical tillage; and (3) selecting the proper herbicides. More adequate methods of controlling weeds after the soybeans have emerged need to be developed.

Soil-Borne Pathogens of Irrigated Soybeans in Egypt

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ABSTRACT: The prevalent soil-borne pathogens on irrigated soybeans are *Fusarium moniliforme*, *F. fusarioides*, *F. oxysporum*, *Rhizoctonia solani*, and *Sclerotium rolfsii*. The soybean cultivars and lines varied in their reaction against infection by soil-borne pathogens. All of the cultivars and lines tested were susceptible to *S. rolfsii*; however, line D 72-7139 was considered as slightly resistant to *R. solani* infection. The Forrest cultivar is considered to be susceptible to the three *Fusarium* sp. tested, while Lee is considered resistant. Line D 75-9125 is considered resistant to *Meloidogyna javanica* and *M. incognita acrita*; however, line D 71-9967 is considered as highly susceptible to *M. javanica*, and as resistant to infection by *M. incognita acrita*. All of the soybean cultivars and lines tested are considered as resistant to infection by *M. incognita acrita*—except the Bragg cultivar, which showed the greatest number of nematodes.

THE SOYBEAN AREA IN EGYPT was almost 40,000 hectares in 1978, depending on irrigation. The diseases caused by soil-borne pathogens are numerous and have been recorded in various parts of the world [Agarwal *et al.*, 1973; Turner, 1964; Boquet *et al.*, 1975; El-Halaly *et al.*, 1972; El-Wakil, 1971; Ibrahim *et al.*, 1972; Kurata, 1960; Mejia, 1954; Mousa, 1979; and Natrass, 1961]. In this paper, the soil-borne pathogens found in irrigated soybeans in Egypt are discussed.

MATERIALS AND METHODS

Soybean plants showing sypmtoms of root rot and wilt were collected from various locations in Egypt. The associated microorganisms were isolated and identified. Pathogenicity tests were carried out on Clark soybeans in pots. Inoculum was prepared using barley grain as the medium, mixed at the rate of 2.5 percent by weight with sterilized soil. Five pots sown with 20 soybean seeds were used as replicates. Controls were included. Data on preemergence damping-off and wilt of the surviving plants were recorded 30 days after transplanting. The reaction of 11 cultivars and lines against *R. solani*, and *S. rolfsii* in pots was recorded using the above-mentioned procedure. Data on damping-off preemergence and postemergence were also recorded.

An evaluation was made of 11 soybean cultivars and lines against *F. moniliforme*, *F. fusarioides*, and *F. oxysporum* using pots with sterilized soil (5 seeds per pot). Ten replicates were used for each treatment. Inoculum was prepared from each isolate on barley grain. Soil infestation was accomplished 1 month after planting. A disease index, developed by the authors, was recorded 45 days after soil infestation, as follows:

1. Healthy plants.
2. Stunting, browning of vascular elements 2 cm long.
3. Stunting, yellowing of vascular elements 5 cm long.
4. More stunting, more yellowing of vascular elements more than 5 cm long.
5. Complete wilting.

The severity of the infection on each species and every cultivar was calculated according to the following formula [Skadow, 1969]:

$$I = \frac{[ak,\ k\ (k-1)]\ x\ 10}{2n}$$

where:

I = Disease index (severity of disease).

ak = Number of plants in each category of infection from 1-5, according to the scale developed by the authors.

k = Type of infection.

n = Total number of plants.

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An evaluation of soybean cultivars against infection by the root knot nematode was carried out. Seeds of each tested soybean cultivar and line were seeded in each of 4 pots (replicates) 25 cm in diameter, filled with sterile, sandy soil. Soil infestation was accomplished by adding 10 egg masses of *Meloidogyne javanica* or *M. incognita acrita* per pot at the time of seeding. The sources of inoculum were: infected roots of night shade (*Solanum nigrum*) by *Meloidogyne javanica* and infected cotton roots (*Gossypium barbadense*) by *Meloidogyne incognita*. The pots received tap water daily and a nutrient solution once a week. Six weeks after seeding, the plants were removed gently. Then, the roots were submerged and washed thoroughly in tap water. Afterward, the soybean roots were stained with cold lactophenol acid fuchsin and stored in the stain for 24 hours. The stained roots were rinsed in water and macerated. Then, the nematode stages were counted, using a dissecting microscope.

RESULTS AND DISCUSSION

The fungi frequently isolated from rotted and wilted plants were *Fusarium moniliforme, F. semitectum, F. oxyspoum, F. fusarioides, F. solani, F. equeseti, Rhizoctonia solani, Sclerotium rolfsii, Mucor* sp., and *Alterneria* sp. About 70 percent of the fungal isolations consisted of *Fusarium* sp. and *R. solani*.

Data on the pathogenicity test of the isolated fungi, presented in Table 1, indicate that the highest percentage of infection occurred with *Rhizoctonia solani*. However, *Sclerotium rolfsii* gave the highest percentage of postemergence damping-off, compared to the other isolated fungi.

Data also indicate that *Fusarium moniliforme* gave the highest damping-off infection, preemergence and postemergence, compared to other *Fusarium* spp. *Alternaria* sp. incited severe infection with preemergence damping-off. *Mucor* sp. gave the lowest infection. These results are in agreement with those in other studies [Agarwal *et al.*, 1973; El-Helaly *et al.*, 1972; El-Wakil, 1971; Kurata, 1960; Mejla, 1954; Natrass, 1961; Turner, 1964].

The data presented in Table 2 indicate that soybean line D 72-7139 was considered as partially resistant to infection by *R. solani*. However, all of the cultivars tested were susceptible to *S. rolfsii* infection.

Table 2. Reaction of Soybean Cultivars and Lines to R. solani and Sclerotium rolfsii in Pots

	R. solani		*S. rolfsii*	
	Preemergence	Postemergence	Preemergence	Postemergence
	percent			
Forrest	60	60	60	100
Centennial	82	100	100	..
Bragg	62	48	87	100
Roanoke	56	58	90	100
Hutton	60	60	60	100
Lee	70	66	90	100
D 72-7139	42	42	90	100
D 71-9966	78	64	90	100
D 71-9967	74	77	90	100
D 75-9925	60	50	100	..
D 75-10172	68	64	100	..
Control	0	0	0	0

Table 1. Pathogenicity Tests for Fungal Isolates of Clark Soybean in Pots

	Preemergence infection	Postemergence kill, remaining seedlings
	percent	
Rhizoctonia solani	100	..
Sclerotium rolfsii	92	100
F. moniliforme	92	55
F. semitectum	78	50
F. oxysporum	64	40
F. fusarioides	64	60
F. solani	42	40
F. equestei	30	20
Mucor sp.	20	20
Alternaria sp.	71	20
Control	0	0

The Centennial cultivar showed a high percentage of damping-off infection, preemergence and postemergence, and was considered as susceptible to *R. solani* infection. However, the soybean cultivars and lines Roanoke, Hutton, D 75-9925, and Bragg were partially resistant to *R. solani*.

Data presented in Table 3 indicate that the Centennial cultivar was most resistant to *F. moniliforme* (2.1 percent infection). However, soybean line D 71-9967 was considered to be most susceptible (43.0 percent infection). In terms of the reaction against *F. fusarioides*, Hutton was considered as most resistant (5 percent infection) and the soybean line D 75-10172 was most susceptible (60.9 percent infection). For *F. oxysporum*, Forrest was considered most susceptible (33.3 percent infection); however, the soybean line D 72-7139 was considered as most resistant (2 percent infection). Forrest could be considered most susceptible to the 3 *Fusarium* sp. tested; and Lee, as most resistant against the 3 *Fusarium* sp. tested.

The data presented in Table 4 indicate that the soybean line D 75-9925 was not infected by both *Meloidogyne* sp. and that it could be considered highly resistant to the 2 root-knot nematodes. Cultivar D 71-9967 showed the greatest nematode population of *M. javanicam* and could be considered as susceptible to that disease, but as resistant to infection by *M. incognita*. Forrest, Centennial, and Bragg soybeans are rated as resistant to infection by *M. javanica*.

All of the soybean cultivars tested were considered as resistant to *M. incognita* infection, except Bragg which showed the highest nematode population. No egg masses were observed on the cultivars infected with the 2 root-knot nematode species.

Our studies indicate that soybean cultivar D 75-9925 was resistant to infection by root-knot nematodes and was also the least nodulated one. This may be due to its well-developed root system that can resist infection. Further studies on this cultivar will be conducted.

The root-knot nematode was the only one noticed in soybean fields, and that rarely.

Soybeans represent a newly introduced crop in Egyptian agriculture. Therefore, the

Table 3. Response of 12 Soybean Cultivars and Lines to 3 Isolates of Fusarium sp. in Pots

	F. moniliforme	*F. fusarioides*	*F. oxysporum*	Mean
		percent		
Forrest	92.0	22.7	33.3	49.3
Centennial	2.1	31.1	21.8	18.3
Bragg	9.3	13.4	28.4	17.1
Roanoke	25.1	18.7	11.4	18.3
Hutton	18.5	5.0	2.2	8.6
Lee	6.5	8.7	6.7	7.3
D 72-7139	19.7	9.4	2.0	10.4
D 71-9966	14.6	9.2	6.7	10.2
D 71-9967	43.0	9.2	7.9	20.1
D 73-9925	10.0	16.0	14.5	13.5
D 73-10232	...	...	...	...
D 73-10172	21.9	60.9	28.0	36.9

Table 4. Reaction of Adapted Soybean Cultivars and Lines to Meloidogyne javanica (M) and Meloidogyne incognita acrita (Mi) 6 Weeks after Inoculation in Pots

	Average (4 roots) number of nematode larvae and females per root					
	M			Mi		
	Larvae	Females	Total	Larvae	Females	Total
Forrest	1.00	0.75	1.75	0	0	0
Centennial	1.25	1.00	2.25	0	0	0
Bragg	0.75	3.00	3.75	3.75	10.0	13.75
Roanoke	11.50	8.75	20.25	0.75	0.5	1.25
Hutton	14.25	8.50	22.75	0	0	0
Lee	6.25	4.00	10.25	0.50	0	0.50
D 72-7139	18.50	4.25	22.75	0	0	0
D 71-9966	7.50	6.75	14.25	0	0	0
D 71-9967	97.00	67.50	164.50	0	0	0
D 75-9925	0	0	0	0	0	0
D 75-10172	20.50	13.75	34.25	0	0	0

pathogens are very rare and are considered of minor importance. Diseases are expected to become economically important following a continous increase in the area cultivated.

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Irrigation Water Requirements and Water Stress

E.T. KANEMASU

ABSTRACT: Seasonal water use by soybeans varies depending on the climate and genotype. Most of the literature reports seasonal water use of 40 to 50 cm, with a peak daily water use of about 8 to 9 mm per day. The variation in yield response to irrigation is large. The yield increase to applied water ranges from 9 to 100 kg/ha/cm of water. Much of the difference can be attributed to several environmental and physiological factors, including the duration and severity of stress, time trend in available water, and growth stage. The most critical stage for adequate water supply is during pod-filling. In some cases, watering during vegetative and flowering stages reduces yields—presumably because of lodging and flower abortion. Apparently, soybean yields are not affected until the root zone has been depleted more than 60 percent. Some of the constraints on efficient production relate to environment-genotype interaction and crop yield modeling. Specific areas of research include programs on the characterization of the rhizosphere, temperature and water-deficit effects on photosynthesis, partitioning and translocation of plant assimilates, and development of a practical model for scheduling irrigation.

SOYBEANS ARE LARGE USERS OF WATER. Kanemasu [1977] reported a peak daily water use of 8.5 millimeters. Doorenbos and Pruitt [1977] presented the seasonal evapotranspiration (ET) range for many crops. The range reflects the climatological, physiological, and morphological differences as well as the length of the growing season. Their ET range was 45 to 82 cm for soybeans. A range in ET values of 25 to 73 cm is shown in Table 1.

Under most conditions the soybean plant cannot differentiate between water applied by nature and that applied by man, so we can consider irrigation as a supplemental source of water for the growth and development of the plant. If the ET rate exceeds the combined amount from precipitation and irrigation, the soil-water reservoir is depleted and the plant may become stressed. Stress can be reflected in the rate of plant development, dry-matter production, or seed yield.

The purpose of irrigation is to provide an economic return by alleviating water-deficit conditions. The economic return will depend on the stage of plant development and on the duration and severity of stress. This paper discusses the timing of irrigation in relation to plant development and the effects of water deficits on the growth and yield of soybeans.

Table 1. Season Evapotranspiration Rates for Soybeans

	ET seasonal (cm)	Reference
Ft. Collins, CO USA	25-39	Danielson [1977]
Urbana, IL USA	39	Peters and Johnson [1960]
Davis, CA USA	48	Beard and Knowles [1973]
Bushland, TX USA	34-68	Dusek, Musick, & Porter [1971]
Manhattan, KS USA	52	Kanemasu [1977]
Oakes, ND USA	50	Carvallo *et al.* [1975]
New South Wales, Australia	73	Thompson [1977]

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LITERATURE REVIEW

The response of soybeans to irrigation water management has been studied by: (1) varying the number and amount of irrigations per season [Khan and Ali, 1969; Matson, 1964; Beard and Knowles, 1973]; (2) varying the soil moisture level before irrigating [Overton *et al.*, 1971; Cassel *et al.*, 1978]; and (3) irrigating at specific growth stages [Dusek *et al.*, 1971; Ashley and Ethridge, 1978; Lawrence and Habetz, 1976; Danielson, 1977].

As anticipated, increasing the amount of irrigation usually improves yields, e.g., from 27 to 54 kg/ha with each cm of added water in Tennessee [Overton *et al.*, 1975]; 75 kg/ha with each cm of added water in Nebraska [Somerholder and Schleusener, 1960]; 9 to 64 kg/ha/cm of added water in Texas [Dusek *et al.*, 1971]; 13 to 21 kg/ha with each cm of water added in California [Miller and Beard, 1967]; and approximately 100 kg/ha with each cm of water added in Hyderabad, India [Khan and Ali, 1969]. The differences between years at one location and between locations stemmed primarily from the initial moisture content of the soil, precipitation patterns, duration and severity of stress, and growth stages at which the plants were stressed.

Where the number of irrigations was varied, soil moisture would depend on the precipitation and irrigation patterns in addition to ET; so, no two years would be identical. Similarly, treatments in which the soil moisture was not allowed to go below certain levels would have a different pattern of soil moisture each year, depending on precipitation and water use. An additional complexity is superimposed on each method of assessing crop response to irrigation—the development and growth stage of the plant.

Several investigators have recognized the importance of the growth stage in managing irrigation. Therefore, instead of maintaining the soil moisture above a specified level, e.g., greater than 2 bars tension in the upper 60 cm of the root zone, water was added at specific growth stages.

Shaw and Laing [1965] studied the effects of water deficits at selected periods during the flowering, pod-initiation, and bean-filling stages. Stress was applied at one of those stages and avoided during the remainder of the season. Yields were reduced the most when plants were stressed during the pod-filling stage. Component analysis indicated that yield reduction resulted from fewer beans per pod. Stress during flowering reduced the number of pods.

Ashley and Ethridge [1978] irrigated soybeans in Georgia at various growth stages and found a large cultivar interaction. Irrigation during the period of vegetative growth had little effect on yields. However, Stone *et al.* [1975] reported that irrigation during vegetative stages significantly increased lodging and could seriously affect the yields of the taller cultivars. Severe stress during vegetative development may reduce stand or plant stature enough to affect yield. Doss *et al.* [1978] found during a 3-year study in Alabama that the pod-filling stage was the most critical one for adequate water, which was consistent with results in Nebraska [Somerholder and Schleusener, 1960]. Matson [1964] found that irrigating during the period from the bloom stage to pod-fill was as effective as irrigating over the entire season.

CURRENT RESEARCH AND DEVELOPMENT

Danielson [1977] obtained a considerable amount of data on the effects of irrigating at specific growth stages by using a continuous, variable, irrigation-line source. In this design, a single sprinkler line was extended through the center of the field parallel with the rows. This irrigation design provided a uniform water application parallel to the line source, but a decreasing application away from the source. Hence, the rows farthest from the sprinkler line received the least water, while those nearest to the line received the most. Danielson applied water at the flowering, pod-development, and bean-development stages. He hypothesized that a resistance mechanism of the deposition of lipids and waxes on the leaf surface reduced water loss during flowering, but was not operative later.

Constable and Hearn [1978] studied the effects of irrigation on an indeterminate (Bragg) and a determinate (Ruse) cultivar in Australia. Both cultivars responded similarly to the irrigation treatments, which varied during pre- and post-flowering (Table 2). Yields were similar regardless of the number of irrigations or timing. The nonirrigated treatments indicated a 35 percent decrease in yields, mainly due to smaller seeds.

At maturity, nonirrigated Ruse and Bragg cultivars had depleted the maximum available water in their rooting zone by more than 60 percent [Burch *et al.*, 1978]. Dusek *et al.* [1971] found that there was no yield reduction at 60 percent depletion. Apparently, soil water depletions of about 60 percent can be imposed on soybeans without significantly affecting yields.

Table 2. Yield and Seed Weight of Two Soybean Cultivars Grown under Five Irrigation Regimes

No. of Irrigations	Yield (kg/ha)			Seed weight (mg/seed)		
	Ruse	Bragg	Mean	Ruse	Bragg	Mean
5	2,737	2,943	2,840	169	198	184
4	2,593	3,003	2,798	169	198	183
3	2,533	3,097	2,815	153	191	172
2	2,660	2,750	2,705	163	180	172
0	1,707	1,919	1,808	119	143	129
S.E.			153			2

Source: Constable and Hearn [1978].

A decline in the dry weight of the stem during pod-filling suggests a translocation of carbohydrate from the stem to the grain that could make up for a decrease in photosynthesis. The two cultivars in the Australia study differed in their translocation responses to water treatment. Ruse (determinate cultivar) indicated a 25 percent yield contribution from the stem, while only nonirrigated Bragg (an indeterminate) appeared to use stem storage (19 percent). Constable and Hearn [1978] suggested that the Bragg cultivar was sink-limited and did not require stored carbohydrate; therefore, the stored reserves were available in case of reduced photosynthesis. Further analyses are required on other genotypes.

Photosynthesis in soybeans is reduced during water stress, and a significant reduction coincided with decreased water potentials and stomatal conductance. Turner *et al.* [1978] found that photosynthesis started to decline at leaf water potentials of about -16 bars. Several species adjust their osmotic potential to maintain turgor and stomatal opening. However, Turner *et al.* [1978] did not find any evidence of osmotic adjustment by soybeans. Osmotic adjustment (osmoregulation) may permit the plant to adapt to water deficits and perhaps may enable the plant to continue to photosynthesize moderately.

Reduced photosynthesis during pod-filling can be partially compensated for by the translocation of assimilates; however, water deficits that cause a substantial reduction in leaf area and hasten development with the subsequent shortening of the pod-filling period can significantly reduce seed size and yield [Thompson, 1977].

CONSTRAINTS ON EFFICIENT PRODUCTION

If more efficient production can mean greater production per unit of water used, both yield improvement and water utilization must be addressed. Increased yields have been reported from narrow rows and were attributed to a more efficient exploitation of moisture from the soil profile [Peters and Johnson, 1960]. Genetic selection of genotypes for specific environments should be explored. Deeper root proliferation would increase the availability of soil moisture [Reincosky and Deaton, 1979].

Improved yields can be accomplished by increasing the seed set, seed weight, or both. Seed set and seed weight were strongly related to canopy photosynthesis from bloom to pod-fill. A significant reduction in canopy photosynthesis has been observed during the afternoon. The hypothesis is that higher air temperatures imposed greater transpirational demand on the leaves and created a water deficit or stress in the photosynthetic system. Sumayao and Kanemasu [1979] found that the temperature of the leaves of well-watered soybean plants was consistently lower than the air temperature; therefore, sensible heat[1] from the air to leaves becomes an additional source of energy for transpiration. However, as the air temperature (Ta) increased (Ta > 32° C), leaf temperatures also increased.

Research at CIAT (Cali, Columbia) compared canopy temperatures of irrigated and nonirrigated treatments with estimated yield responses [D.R. Laing, personal communication]. That effort is in the initial stages, but the preliminary results appear to be promising.

My hypothesis is that genotypes with the highest canopy temperatures under well-watered conditions should respond the best under stress conditions. To test such an hypothesis, a large range of germplasm is required. Since technology has provided instrumentation (infrared thermometry) to routinely measure canopy and leaf temperatures, at least a modest effort in this regard seems appropriate.

Additional studies simply applying water and measuring only the yield do not seem to be useful. But studies concerning plant responses and adaptations to water and temperature changes are to be encouraged. To

[1]Sensible heat here refers to the energy available for transfer by convection from the surrounding air to the leaf surface.

effectively schedule irrigation, a physiological crop model must be developed. Such a model must incorporate not only the soil water balance and appropriate crop response functions (e.g., translocation, partitioning of plant assimilates, photosynthesis, etc.), but also the crop development. Only readily available or easily measured inputs should be used. Such yield and growth models can then be interfaced with economic models to optimize water, energy, and costs.

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Irrigated Soybeans and the Production of Other Legumes on the Latosols of Sri Lanka

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ABSTRACT: This paper reports on the irrigation needs of soybeans when grown on latosols in Sri Lanka. High yields were obtained with irrigation, ranging from 3,000 to 6,000 kg/ha on research plots. In farmer's fields, yields averaged 2,000 to 2,500 kg/ha. Irrigation is from groundwater, so the exact water requirements at different stages of crop production must be determined. Lysimetry experiments were conducted to determine the rate of evapotranspiration (ET). Potential evapotranspiration (ETpot) was computed using the Penman equation. Evaporation from the class A Pan (E_o) was monitored. The following values were recorded at the major stages of development: early growth stage, $ET/E_o = 1$; flowering stage, $ET/E_o = 1.1$; pod-development stage, $ET/E_o = 1.15$; and bean-filling stage, $ET/E_o = 1.2$. Hence, yields may be adversely affected if the crop is stressed during the latter part of pod development and during the bean-filling stage.

To study soybean response under different water availability in the soil, an experiment was conducted, irrigating soybeans at three levels of water stress: 0.26 to 0.33 bars of mercury, 0.39 to 0.46 bars, and 0.52 to 0.59 bars. The experiment is still in the field, so conclusions about pod-size development and yields cannot be made. However, the results to date indicate that at the highest stress (0.52 to 0.59 bars), pod development is advanced and less vegetative growth occurs.

Potentially, the acreage of soybeans as an alternate crop on the latosols of the north and northwest regions of Sri Lanka can be increased. Farmers are looking forward to diversifying the present cropping systems because of the high cost of chemicals and of groundwater irrigation. Initial investigations indicate that soybeans need relatively less chemicals and irrigation water than other possible crops. With good management, very high yields have been obtained at the Agricultural Research Station in Thirunelvely.

Irrigation has frequently promoted more vegetative growth and has retarded pod development. Thus, the irrigation requirements at different stages of crop growth for soybeans need to be determined.

THE LATOSOL SOIL IN SRI LANKA is mainly confined to the north and northwest regions (Figure 1). The land area in the region is 0.6 million ha, of which approximately 15,000 ha could be brought under cultivation through double-cropping, and with groundwater irrigation. In addition, a considerable amount of land could be used for soybeans under rain-fed cultivation during the Maha.[1] At present, only 6,250 ha are intensively cultivated, mainly on the Jaffna Peninsula. Groundwater is found in the Miocene limestone aquifer below the latosols.

[1]The wet-weather period, October to December.

The climatic conditions and excellent drainage properties of the soil suggest a high potential for the production of soybeans and other legumes using controlled-lift irrigation. Lifting groundwater for irrigation, however, has become very costly recently. Hence, the exact water requirements of soybeans and other legumes must be known so efficient irrigation systems for such crops can be designed.

CLIMATE

The north and northwest dry zones of Sri Lanka have a relatively low annual

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Figure 1. Map of Sri Lanka.

rainfall. The mean is 900 to 1,500 millimeters. There are long drought periods each year, even in the Maha. The variability is such that the climate is unreliable for raising only rain-fed crops. The temperature is rather hot. The average is 20° C over the year, but the nights are cool enough during the late Maha (January to May) to favor the growth of soybeans, mung beans [*Vigna radiata* (L.) (Wilczek)], some temperate crops, and a wide range of tropical crops. Evaporation in the dry weather (June to September) is relatively high, aggravated by windy conditions. The soil temperature during that period is 35° to 40° C at a depth of 10 cm, creating production limitations in raising soybeans and mung beans.

SOILS

Among the soil and landform units in the north and northwest regions, about 33 percent is red yellow latosol [Pannabokke, 1967]. The soil is deep and is highly permeable. Some of the best soils are suitable for irrigated legumes.

The soil fertility is moderate to low. Thus, fairly high inputs of organic manure and fertilizers are required. In the northern tip of Sri Lanka (the Jaffna Peninsula), the latosol soils are shallow and contain moderately nutrient-retentive clay.

SOYBEAN AND MUNG BEAN CULTIVATION

These crops were cultivated for a long time in Sri Lanka. During the last few years, however, a systematic evaluation was initiated of variety performance, planting time, and the effects of pests and diseases. Generally, several varieties of soybeans did better when planted in March and April so that they matured during the rainless, hot-weather period. Although cooler temperatures prevail in January and February, the incidence of pests and diseases is greater because of the high humidity.

The best time to plant mung beans is in late November. With supplementary irrigation, that crop matures during February, a relatively cool period (Tables 1 and 2).

Table 1. Results of Soybean Variety Trials Conducted at the Agricultural Research Station, Thirunelvely (Jaffna Peninsula), Sri Lanka, 1975

Soybean variety	Period	Days to harvest	Mean yield (kg/ha)
Jupiter	April-June	120	4,409
Bossier	April-June	107	5,831
Pb-1	April-June	105	5,655
SJ-1-2	April-June	104	4,075
Hardee	May-August	113	6,050

Table 2. Results of Mung Bean Variety Trials Conducted at the Agricultural Research Station, Thirunelvely (Jaffna Peninsula), Sri Lanka, 1978-79

Mungbean variety	Period	Days to harvest	Mean yield (kg/ha)
MY-50-10	November-February	73	2,139
CES-87	November-February	73	2,162
H-101	November-February	73	2,106
MJ-1	November-February	73	2,211
MJ-4	November-February	73	1,930

CROPPING PATTERN ON THE JAFFNA PENINSULA

There are about 12,000 dug wells in the Peninsula irrigating about 6,240 hectares. The farmers have invested in water pumps and have constructed dug wells on their own holdings. With these facilities, a very intensive system of cultivation is practiced; normally two or three crops a year. During the early part of the year, cool-season crops (mostly temperate types) including tobacco, potatoes, and chili peppers with an 8-month maturation are grown. Soybeans are often intercropped with chilies. During the hot weather (June to September), onions, chilies, and legumes are grown; in the wet weather, a green manure crop is grown. To maintain this system of cultivation, costly pesticides are being used to control pests and diseases.

The two major crops, chilies and onions, are irrigated frequently. With the recent increase in the price of fuel, it costs about Rs. 2,500 (U.S. $167), to lift the water needed to irrigate an acre of the chili crop over the 8 months. Because of these constraints, farmers are prepared to diversify the cropping pattern.

Quite recently, more soybeans and other legumes have been grown. To encourage the cultivation of these crops, the State has offered a favorable price for soybeans. Therefore, considerable land in the north and northwest regions will be planted with soybeans in the future.

EXPERIMENTS

Irrigation Requirements for Soybeans

Water management studies for soybeans and other legume crops were initiated in early 1978 at the Agricultural Research Station near Thirunelvely on the Jaffna Peninsula. The consumptive water use by soybeans was determined by growing the crop in 5 lysimeters placed side by side. The lysimeters were of the interval drainage type as described by Hudson [1964], i.e., 120 cm square and containing soil to a depth of 90 centimeters. They were located at the center of a square plot of soybeans 0.75 ha in size. The variety grown was Tracy, with 3 months maturity. In the lysimeters, the seeds were sown in rows 45 cm apart and 10 cm between plants in the row. One plant per hill was maintained in all 5 lysimeters. Plants inside and outside the lysimeters received the same fertilizer applications, irrigation treatments, and the like in order to minimize the variation in crop growth and exposure. Irrigation was provided when the soil moisture reached a water stress of 0.33 bars,[2] indicated by tensiometers buried at a depth of 15 centimeters. The results, plotted in Figure 2, are listed below:

1. Weekly average of evapotranspiration (ET) from lysimeters (means for 5 lysimeters).
2. Potential evapotranspiration (ETpot) by the modified Penman equation from Pruitt [1960].
3. Class A pan evaporation (EO).

The following conclusions were drawn:

1. Soybeans appear to be very specific in their demand for water at different stages of growth. The mean values obtained were: (1) germination to flowering stage, ET/E_o = 1; (2) flowering stage (fourth to sixth week after planting), ET/E_o = 1.1; (3) pod development (sixth to eighth week after planting), ET/E_o = 1.15; and (4) bean-filling stage (eighth to eleventh week after planting), ET/E_o = 1.2.
2. Thus, maximum reduction in yield could be expected if moisture stress was to occur during the latter part of the pod-development and bean-filling stages. Mederski, Jeffers, and Peters [1973] observed the same trend in their investigations.
3. From the eighth to the eleventh week after planting, the ET rates were significantly higher than open pan rates and remained constant regardless of changes in the weather. During that period, ET is entirely a function of the crop stage and is not governed by the environment. Interestingly, Anulanthi [1979] found that in the same period, the moisture percentage of the seed dropped by an insignificant amount (7 percent); but from the eleventh to the thirteenth week, it dropped by 50 percent.

Evaluating the Water-Use Requirement of Soybeans

The consumptive use of irrigation (water use requirement) water as monitored by the lysimeters was ET = 529 millimeters. The class A pan evaporation during the growth of the crop was E_o = 533 millimeters. The potential evapotranspiration according to the Penman equation was ET_{pot} = 508 millimeters.

[2]One bar = 1,035 cm of water = 76.5 cm of mercury.

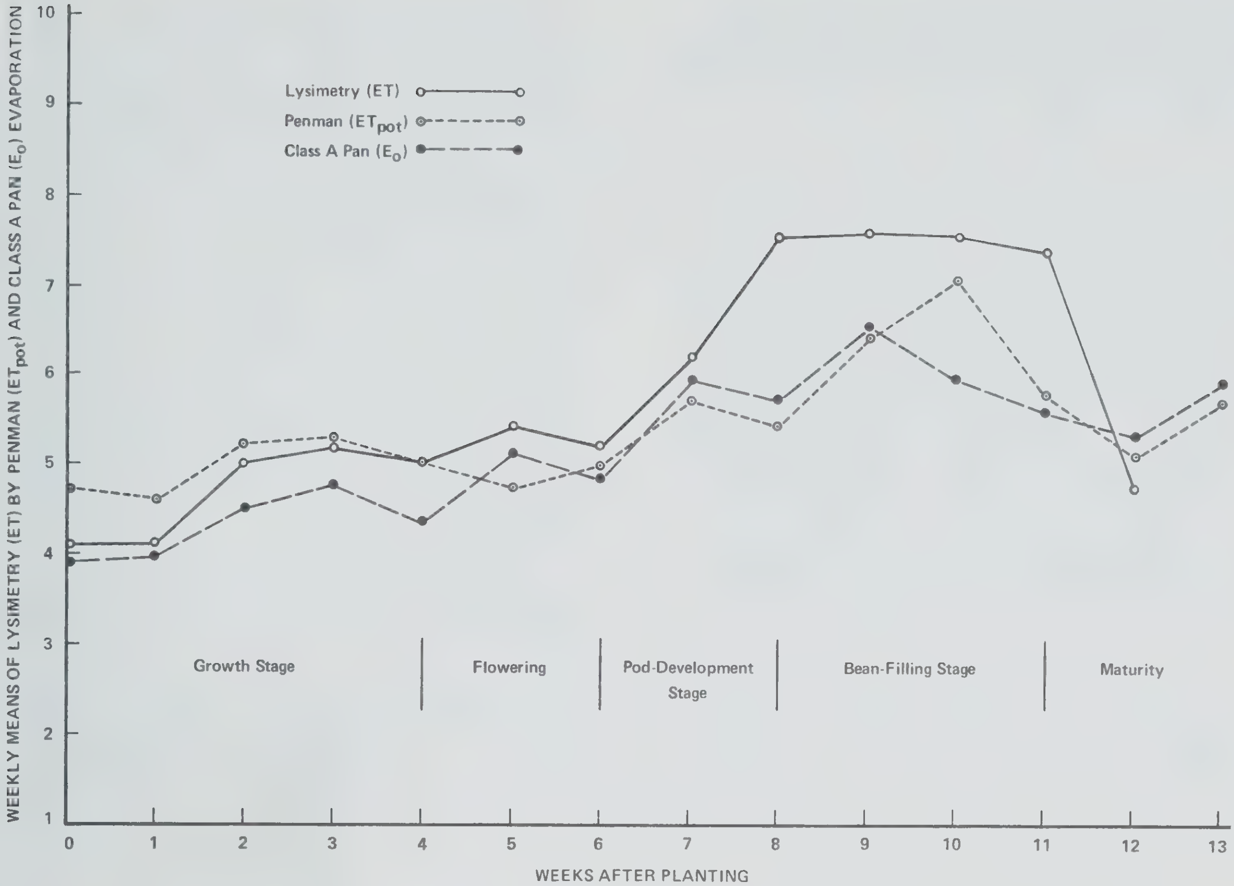

Figure 2. Weekly means of evapotranspiration (ET) by lysimetry, potential evapotranspiration (ET_{pot}) by Penman and class A pan evaporation (E_o).

Throughout the crop growth period there was only 15.8 millimeters of rain, which occurred during 3 days—April 23, 24, and 28. Since the crop was harvested on May 2, this source of water was not available to the plants and can be ignored.

The yield of the crop in the lysimeter was 0.4 kg/m^2 or 4,000 kilograms per hectare. The yield of the crop in the field was 2,950 kilograms per hectare.

The estimate by lysimeter for the total consumptive use of irrigation water appears to be too high. It is almost the same as the value obtained with the class A pan. Since rainfall occurred during the last week before harvest, the quantity of water remaining in the lysimeters after harvest might have been overestimated. However, the lysimeter method pinpointed the different periods of water stress for the soybeans. In order to predict the water demand from agro-meteorological records, the Penman computation of ET_{pot} was made from the well-known equation:

$$ET_{pot} = \frac{\Delta Q_n + \gamma E_a}{\Delta + \gamma}, \text{ where}$$

Q_n = net radiation in langleys (cal/cm^2)/day

U_2 = wind speed in miles/day at height of 2m

γ = Boltzman's constant (0.43)

Δ = slope plot of saturated vapor pressure vs. air temperature in °F

$E_a = 0.35 = (l_a - l_d)\ (1+U_2)$, where

l_a = saturated vapor pressure in mm of Hg at mean temperature

l_d = saturated vapor pressure in mm of Hg at dew point.

The agro-meteorological station at the Research Centre had instruments to measure incoming radiation; maximum and minimum temperature; wet- and dry-bulb temperatures; day length; and class A pan evaporation. Weekly averages of these data were used to establish the various parameters in the Penman equation.

Since the equation did not contain factors for growth stages, the plot of the Penman data was not in step with that of the lysimetry data. In general, Penman methods appear to be underestimated. There might have been errors in some of the

assumptions made (reflection coefficient and so on). Hence, instruments to monitor these coefficients would be required for a better estimate.

Three Moisture Regimes

The experiment was conducted at the Research Station near Thirunelvely on the Jaffna Peninsula. At the surface, the calcic red yellow latosols of the Jaffna Peninsula have 32 percent coarse sand, 42 percent fine sand, 12 percent silt, and 23 percent clay. The bulk density (1.48 gm/cm^3) creates a total porosity of 44 percent. At deeper layers, the clay content is greater. The relevant data for irrigation purposes are given in Table 3 [Joshua, 1973].

About 80 percent of the available water is depleted within one bar stress. Thus, the range of available moisture is small.

Sivanayagam [1973] conducted several experiments on irrigated corn and chilies at different tensions. The studies were done at the Maha-Illupalama Research Station in the dry zone of Sri Lanka. He found water availability became limiting and affected growth beyond a 50 percent depletion of the available water, which occurs at a stress of 0.33 bars.

The experiment of irrigating soybeans at three different water stresses is still in progress at the Jaffna Research Station. However, relevant data collected to date can be given to highlight some of the differences in the growth parameters.

Soybeans were planted on June 29, 1979. The treatments were irrigation to a water stress of 0.26 to 0.33 bars, 0.39 to 0.46 bars, and 0.52 to 0.59 bars. Each treatment had 4 replicates.

Records of dry-matter production, leaf area, and pod count at the three water stresses are given in Figures 3 and 4. The

Table 3. Physical Properties of the Calcic Red Yellow Latosols of the Jaffna Peninsula

Water at field capacity (%)	Water at the plant wilting point (%)	Total available water (%)	Water per meter of soil (cm)	Stress at field capacity (bars)	Stress at 50 percent depletion (bars)
14	7	7	10	0.1	0.33

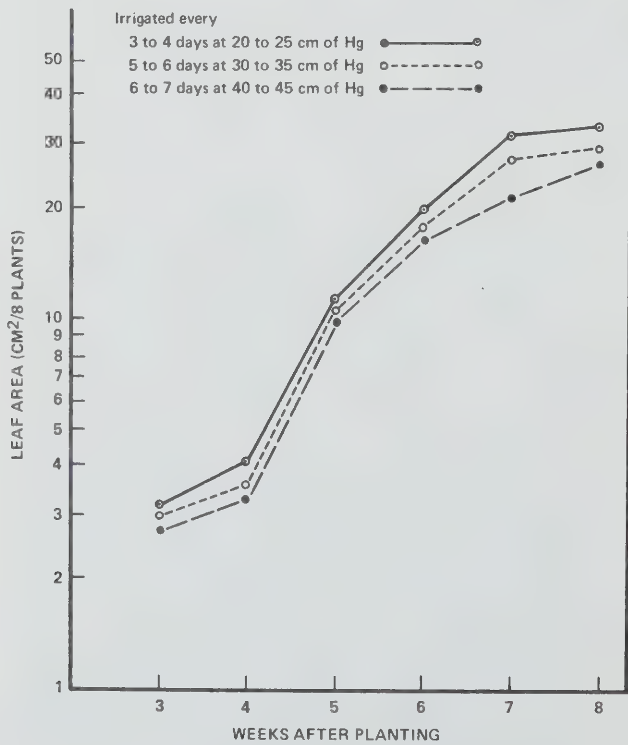

Figure 3. Leaf area of soybeans irrigated at different soil moisture tensions, measured in mercury (sample size, 8 plants).

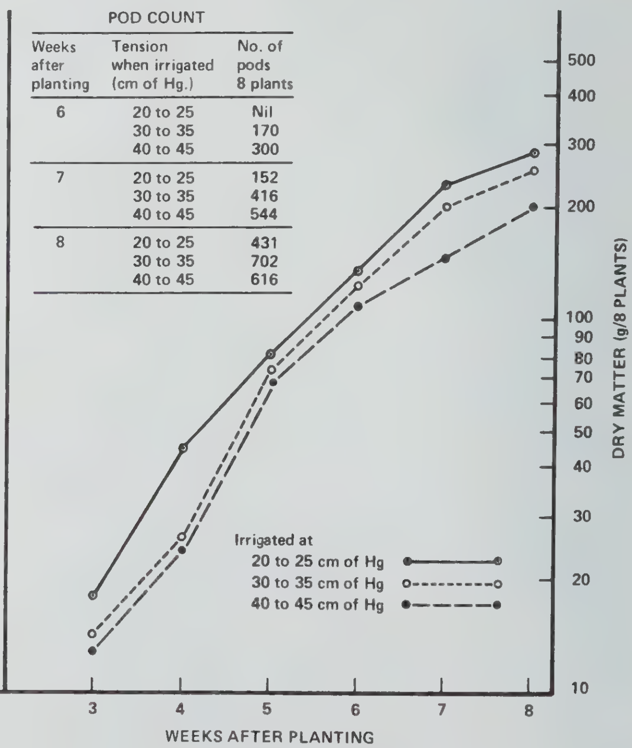

Figure 4. Dry matter production and pod count of soybeans irrigated at different soil moisture tensions, measured in mercury (sample size, 8 plants).

leaf area was determined by using the punching technique described in Vivekananthan [1977]. The technique is simple and correlated well with other methods. At the highest water stress (0.52 to 0.59 bars), vegetative growth appeared to be slower and pod development faster. Since the experiment is still in the field, definite conclusions cannot be made about pod development, bean filling, seed size, and yields.

CONCLUSION

Soybeans need water and other inputs compared with the traditional crops of chili peppers and onions grown in the north and northwest regions of Sri Lanka. Irrigated soybeans and mung beans have given high yields on the latosol soils. Because of the high cost of lift-water irrigation, determining the actual consumptive water requirement at various growth stages is important. Although an attempt was made to determine the requirement during early part of the year, the study should be repeated for different planting times. To predict the evapotranspiration from agro-meteorological records, more instruments would be required to determine net radiation, the crop coefficient, and the like.

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Research on Drought Resistance and Irrigation of Soybeans in Parana, Brazil

S.R. WANG, G.M. WANG, E.F. QUEIRÓZ, AND C.M. MESQUITA

ABSTRACT: The capacity of the soybean plant to survive wilting is an important factor in drought resistance. Drought resistance in soybeans was characterized according to physiological parameters. The degree of resistance by soybean plants to water loss was determined, ranging from 40.7 to 52.3 percent in the soybean cultivars tested. The stomatal behavior in response to water stress was observed. The effect of applying abscisic acid to prevent water loss was also studied.

The effect of irrigation on soybean production in the field was investigated. Irrigation increased the: plant height; leaf area; dry weight of leaves, roots, and stems; length of primary root; and number of leaves. Increased leaf water potential contributed to plant growth through greater turgidity and also minimized the effect of water stress in reducing photosynthesis.

The increase in the number of leaves (17.8 percent) was less than that in leaf area (53.5 percent). Irrigated soybeans developed larger leaves, mainly in the upper part of the plant. This was confirmed by a greater dry weight for the leaves (49.7 percent). The effect of irrigation was more pronounced on the growth of aerial parts (49.4 percent) than on roots (36.5 percent).

The increase in production by irrigation was 123 kilograms per hectare. That value is not very high, possibly because there was no water stress on the crop at the pod-filling stage in this experiment.

IN NORTHEAST BRAZIL, rainfall is a limiting factor in soybean production. Even in the central region, occasional dry periods of 2 to 3 weeks occur during the growing season. These periods are important to the development of agriculture. During such times, the soil may become very dry because of its low capacity to hold water.

A water deficit can reduce soybean growth by modifying the physiological processes. Insufficient water during the pod-filling stage can be a major barrier to higher soybean yields. Doss *et al.* [1974] reported a greater response when water was supplied after full flowering than when applied earlier. The conclusion from the study was that soybean yields were most sensitive to water stress during the pod-filling stage. Spooner [1961] found little or no benefit from irrigation before flowering and concluded that irrigation could be utilized best during the fruiting period. Irrigation during the early stages of growth was not beneficial according to Grissom *et al.* [1955].

Mederski [1973] observed that cultivars differ greatly in their capacity to withstand moisture stress. Under a high moisture deficit, stress-resistant cultivars showed yield reductions of about 20 percent compared to 40 percent for cultivars less resistant to moisture stress. The yield reduction for all cultivars ranged from 150 to 750 kilograms per hectare.

The work described in this paper was designed to select soybean cultivars that would be more tolerant to occasional deficiencies of water using physiological parameters; also, to verify the effect of irrigation on the growth and production of soybeans.

MATERIAL AND METHODS

In 1978, soybeans were grown in a red latosol soil in Londrina, located in the north part of the Parana State in Brazil. Leaf samples to determine critical saturation deficits were taken when the plants had reached their maximum development. The

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method used was described by Weinberger *et al.* [1972]. Thirty-six leaves of similar size were selected from each cultivar, taken from plants with petioles of 1.5 cm. To obtain the maximum saturation weight (Wmax), the petiole of the leaves was immersed in a cup of water inside a chamber saturated with water vapor. After 20 hours, the excess water on the leaf was removed with paper and the Wmax value was determined.

The leaves were then allowed to desiccate in the laboratory until they had lost 30, 40, 50, 55, 60, and 65 percent of their maximum weight. After reaching the predetermined minimum weight for each treatment, the petiole was cut longitudinally and put into water in a test tube. After 48 hours inside the saturation chamber, the leaves were weighed to establish the resaturation weight (Wre). Finally, the leaf dry weights (Wd) were measured after drying the material in an oven at 70° C for 24 hours.

The critical saturation deficit represents the value of the saturation deficit associated with a resaturation of 90 percent. That value was calculated from the regression between two parameters:

$$\text{Saturation deficit} = \frac{\text{Wmax} - \text{Wmin}}{\text{Wmax} - \text{Wd}}$$

$$\text{Resaturation} = \frac{\text{Wre} - \text{Wd}}{\text{Wmax} - \text{Wd}}$$

In order to compare stomatal sensitivity to water stress, soybeans were planted in a greenhouse. The measurement of stomatal behavior was performed by using a diffusive resistance meter LAMBDA LI-60, following the method described by Wallihan [1964] and using the modified sensor described by Kanemasu *et al.* [1969].

The leaf diffusive resistance was measured every 2 hours between 0800 and 1800 hours each day, taking the average of the first 3 readings as a morning mean value and the last 3 for the afternoon mean value. The abaxial diffusive resistance $r_{L(AB)}$ and the adaxial resistance $r_{L(AD)}$ were determined for all cultivars. The total leaf diffusive resistance (r_L) was calculated by using the equation given by Henzell *et al.* [1975]:

$$\frac{1}{r_L} = \frac{1}{r_{L(AB)}} + \frac{1}{r_{L(AD)}}$$

In the field study, abscissic acid (5 g/ml) was applied when the soybeans were in the pod-filling stage. The leaf-water potential was determined on days 5 through 8 after the application.

To evaluate the effect of irrigation on soybean production, the soybeans were planted in red latosol soil. Irrigation was applied when the leaf-water potential was measured using the pressure-chamber technique of Scholander *et al.* [1965]. This value was obtained between 1600 and 1700 hours.

RESULTS AND DISCUSSION

The resistance to water loss for 16 soybean cultivars is represented in Figure 1 and Table 1. The range was 40.7 to 52.3 percent in the soybean cultivars tested. These values signify the percentage of water that each cultivar can lose in relation to its maximum state of turgidity, while retaining the capacity to recover when the moisture conditions in the soil are reestablished. The cultivar IAC-3 was best in its tolerance to water stress.

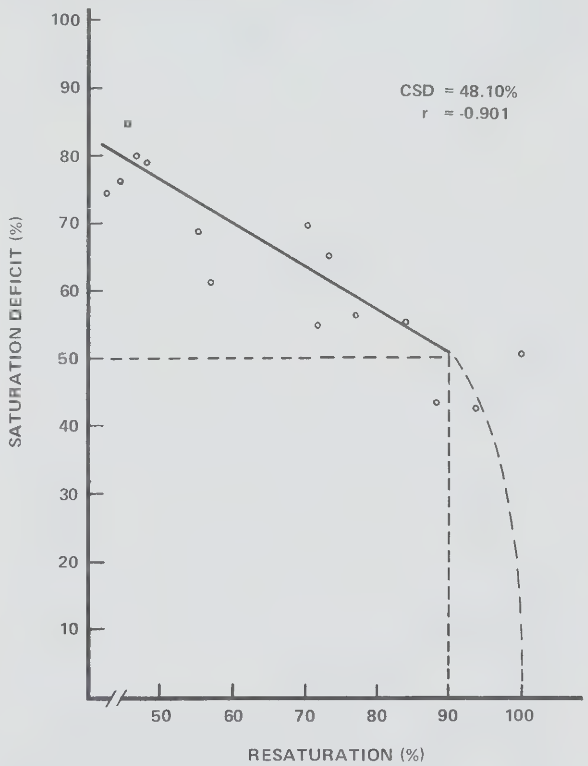

Figure 1. Correlation between the saturation deficit and resaturation of the soybean cultivar Bragg. CNPSoja, Londrina, Brazil, 1979.

Another method of evaluating how well plants can withstand water stress is to determine their resistance to moisture loss at a given water potential. Figure 2 shows the comparison of stomatal sensitivity to water stress for 2 soybean cultivars. With the Davis cultivar, stomatal behavior was similar to that of the control plants during the entire 4-day period of water stress. With the cultivar Hardee, however,

Table 1. Critical Saturation Deficit of Some Soybean Cultivars, CNPSoja, Londrina, Brazil, 1979

Cultivar	CSD	Cultivar	CSD
IAC-3	52.3	Sao Luiz	45.8
Bossier	51.1	Parana	45.1
UF V-1	48.5	Perola	43.9
Bragg	48.1	Andrews	42.3
BR-1	47.9	Mineira	42.0
C. Gerais	46.5	Florida	41.7
IAC-4	46.2	Hardee	40.7
Santa Rosa	45.9	Davis	40.7

3 days after the start of water stress a high diffusive resistance developed in relation to the controls. This means that the Hardee stomates were closed more than those of the Davis cultivar because of a leaf-water deficit; also, that the Hardee cultivar suffered more from the drought treatment, compared to Davis.

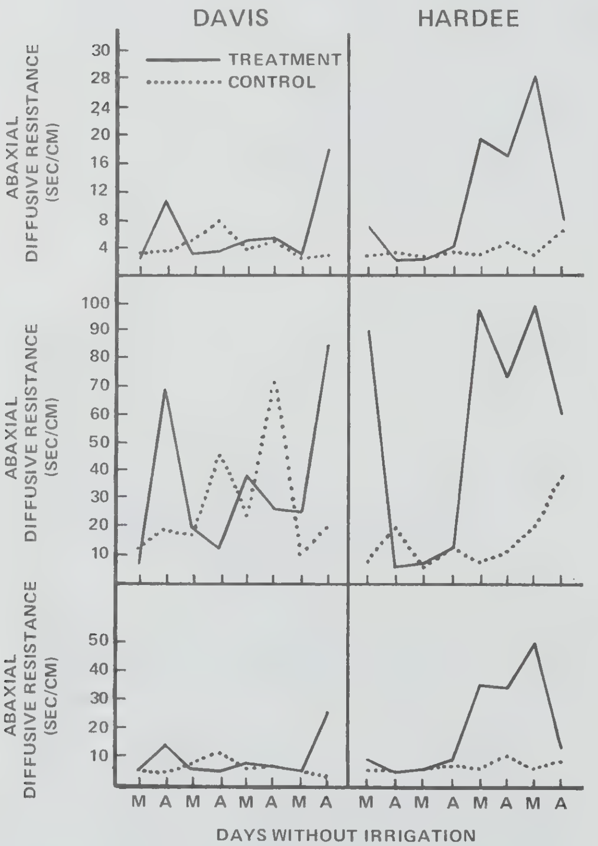

Figure 2. Comparison of stomatal sensitivity to water stress of two soybean cultivars (M = morning, A = afternoon). CNPSoja, Londrina, Brazil, 1979.

Hardee seems to use more water than Davis. During the first 3 days, the Hardee soybeans used all of the available water in the pot; then, under water stress, the stomates began to close from a lack of soil water and the consequent reduction of leaf-water potential.

Figure 3 shows that the soybeans treated with abscissic acid always presented higher values in terms of leaf-water potential than the controls. The abscissic acid seemed to help the soybean plants maintain better leaf water conditions. The principal function of abscissic acid is to minimize the effect of water stress by causing a partial closure of the stomates [Tucker and Mansfield, 1971]. That action is particularly valuable in the critical pod-filling period when the plant is most sensitive to water stress.

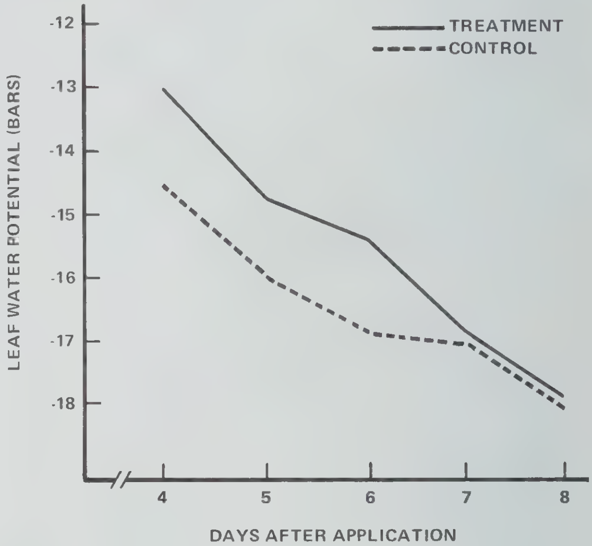

Figure 3. Effect of abscissic acid on soybean leaf water potential during drought, CNPSoja, Londrina, Brazil, 1979.

The results of using irrigation are presented in Table 2. For irrigated soybeans, the test values were higher for plant height, leaf area, leaf area index, leaf dry weight, root dry weight, dry weight of the aerial parts, leaf-water potential, dry weight of the stem, root length, and number of leaves per plant.

The increase in the number of leaves (17.8 percent) was less than that in leaf area (53.5 percent). The irrigated soybeans developed some new leaves, especially in the upper parts of the plant, and the leaves were considerably larger, too. The increase in dry leaf weight (49.7 percent) confirmed the change.

Table 2. *Effect of Irrigation on Soybeans, CNPSoja, Londrina, Brazil, 1979*

Plant characteristics	Nonirrigated	Irrigated	Increase (percent)
Height/plant	57.4 cm	65.8 cm	14.5
Leaf area/plant	1,333 cm^2	2,046 cm^2	53.5
Leaf area index	4.16	6.40	53.5
Leaf dry weight/plant	5.33 g	7.98 g	49.7
Root dry weight/plant	1.75 g	2.39 g	36.5
Aerial dry weight/plant	20.36 g	30.42 g	49.4
Leaf water potential	-19.60 bars	-16.30 bars	16.8
Stem dry weight/plant	15.03 g	22.44 g	49.2
Root length/plant	24.38 cm	26.78 cm	9.8
Number of leaves/plant	51.18	60.35	17.8
Yield (kg/ha)	2,750	2,873	4.4

Mayaki *et al.* [1976] found that under irrigation, the depth of root penetration increased faster than plant height. In our tests, comparing the increase of stem dry weight (49.2 percent) and leaf dry weight (49.7 percent) with the increase of root dry weight (36.5 percent), the effect of irrigation was more pronounced on the aerial parts of the soybean plant than on the roots.

The increased growth found in irrigated plants, however, was caused by the higher leaf-water potential that produced cell turgidity. That turgidity stimulates growth by its support of cellular processes leading to the synthesis of new protoplasm and cell-wall material [Boyer, 1968]. The higher leaf-water potential also favors photosynthetic efficiency [Boyer, 1970] while a deficit of water in the leaves causes the opposite effect, seen especially in an elongation of the stems and an enlargement of the leaves.

Above-normal rainfall during the late-vegetative and bean-filling periods increases the soybean yield [Runge and Odell, 1960]. A direct relationship between rainfall during the pod-filling period and soybean yield has been established [Rogers and Thurlow, 1970]. Brady *et al.* [1974] in a 2-year experiment concluded that irrigation increased soybean yields by about 20 percent and that only a third to a half of the water necessary for full-season irrigation could produce equally good yields if it were applied during the pod-filling stage. In our field experiments, the increase in yield due to irrigation was 123 kg/ha (4.4 percent). The value was not high, probably because of the absence of water stress in the control crop during the pod-filling stage.

CONCLUSIONS

Under the conditions that prevailed during the year of our experimentation, it would not have been economical commercially to grow irrigated crops of soybeans. In drier years, irrigation might be an economical proposition. More production studies will be needed to determine that.

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Irrigation Systems for Soybean Production

D.R. HAY

ABSTRACT: Optimum production of soybeans under irrigation requires a properly selected, designed, and managed irrigation system. The factors to be considered in selecting the system include: topography; soil characteristics; the source, amount, and quality of the water supply; crop characteristics; and the labor and capital available. The criteria for evaluating an irrigation system include: uniform distribution of water; minimum erosion or other damage to the land; maximum application and water-use efficiency; as well as practical and economical performance from the standpoint of the crop, labor and energy requirements, cost of land preparation, and maintenance costs.

The two basic methods of irrigating soybeans are surface (gravity) and sprinkler. The most common surface methods of irrigating soybeans are the basin, border, and furrow systems. Furrow systems may use varied row spacings or bed-planting configurations. The most common sprinkler systems used for soybeans are center-pivot, side-roll, traveling-gun, tow-line, and solid-set. The proper land preparation must be accomplished during the development of an irrigated field. Where required, drainage must be an integral part of the irrigation system. The characteristics of the specific site for soybean production must govern the selection of an irrigation system.

REALIZING OPTIMUM SOYBEAN PRODUCTION under irrigation requires a properly selected, designed, and managed irrigation system. The system should be designed to fit the conditions of the field where it is to be used. Some of the major factors affecting the selection and operation of an irrigation system include: topography, soil characteristics; the source, amount, and quality of the water supply; crop characteristics; and the labor and capital available. Other factors include land preparation; field size; salinity conditions; groundwater and drainage; available power; crop rotations and cultural operations; crop yields and quality; climatic conditions; crop insects and diseases; the cost of the water; depreciation, operating, and maintenance costs; and socioeconomic considerations.

The term "irrigation application efficiency" is often used to evaluate irrigation systems being used to try and reach the maximum possible efficiency. Irrigation application efficiency can be defined as the ratio of the amount of water stored in the soil during an irrigation for use by the plant to the amount of water delivered to the field. Other criteria that should be considered in evaluating an irrigation system include: (1) uniform distribution of water; (2) minimum erosion or other damage to the land; (3) maximum water-use efficiency; and (4) practical and economical performance from the standpoint of the crop, labor and energy requirements, cost of land preparation, and maintenance costs. With concerns increasing about the cost and availability of energy, the energy requirements of an irrigation system must be considered carefully, too.

The literature does not contain major studies comparing irrigation systems for soybean production. There has been a considerable effort to evaluate various water-management alternatives, but little effort regarding system effects or suitability. Bishop [1977] noted that "agricultural crops have no preference as to how water arrives at [the] root system." Soybeans probably can be irrigated with most irrigation systems as long as the system is managed to meet the water requirements of the crop. In many cases, new irrigated production of soybeans will be considered for areas with

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existing irrigation. In such cases, the improvement and management of the existing irrigation system is the concern, rather than the design of a new system.

IRRIGATION METHODS

The two basic irrigation methods used for soybeans are the surface and sprinkler systems. The common surface methods that can be used to irrigate soybeans include the basin, graded-border, and graded-furrow systems. The common sprinkler systems used for soybeans include laterals moved by hand, tow-line laterals, side-roll laterals, traveling big guns, and center-pivot units. Stationary big guns, solid-set units, and boom-type sprinklers are less common, but could be used for soybeans.

A brief discussion of irrigation methods follows, with general descriptions and guidelines. Detailed design information is available from many sources and is included in a number of the references. The literature contains many descriptions of irrigation methods and systems for those who want more detailed information. Such sources include Bishop [1977], Hagen [1973], and Israelsen and Hanson [1962].

Surface Units

Surface irrigation is of importance worldwide. The majority of the irrigation done is accomplished that way. With its low energy requirement, surface irrigation will continue to be of importance. Booher [1974] and Bishop *et al.* [1967] provide good general references about surface irrigation. The science of surface irrigation continues to advance. Even so, considerable skill and talent are required by the irrigator for effective results.

Surface irrigation can be used with many types of soils and conditions. A surface system can be designed for a wide range of water-flow rates while still maintaining high application efficiencies. Two requirements of prime importance in utilizing surface methods are: (1) distribution systems constructed to provide adequate control of the water and (2) land preparation that permits a uniform distribution of water and allows excess water to drain off [Booher, 1974].

With surface irrigation, the water distribution is controlled by the land surface. Normally, the surface of the land must be modified to achieve the desired distribution of the water. Major design considerations include: (1) selecting the proper length and direction of run or basin size; and (2) matching the stream size to the soils and topography.

FURROW SYSTEMS. With furrow irrigation, small channels or furrows are used to move the water over the soil surface in small, parallel streams. The slope of the furrow moves the water across the field. Water can be brought to the furrows by using open ditches with spiles or siphon tubes to place the water in the furrows. Greater water application efficiency can be achieved by lining the ditches to prevent seepage losses.

In the Great Plains of the United States, the water is usually delivered to the furrows by using aluminum gated pipe. Some plastic gated pipe is also employed. The gates on the pipe are spaced so the water can be placed directly into the furrow. The gates can be adjusted to regulate the flow of water in the furrow. Research is currently underway using plastic pipe buried 30 to 45 cm below the surface, with an outlet to each furrow [Worstell, 1976; and Worstell, 1979].

If designed and operated properly, furrow systems can apply water efficiently and uniformly. The design must consider furrow spacing, furrow grade, cross slope, stream size in the furrow, and the length of the run. The furrows must be spaced so the water will be distributed uniformly in the soil, while also accommodating the cultural practices used for the crop being grown.

In Kansas, the common furrow spacings for soybeans are 76 and 152 centimeters. The soybeans are planted on the flat surface with the furrows made after the crop has reached a height of 30 to 60 cm, or on beds made before planting. On 152 cm beds, the most common planting configuration is two rows 76 cm apart. This spacing allows mechanical cultivation to be done easily.

Other planting configurations are also used. The Irrigation Experiment Field at Scandia, Kansas has evaluated two (76 cm spacing), four (39 cm), and six (25 cm) rows on a 152 cm bed. Irrigating the 152 cm beds was comparable to irrigating only alternate rows of soybeans planted in rows 76 cm apart. Results for several years at the Irrigation Experiment Field have shown that yields from alternate-row irrigation (with 76 cm rows) were almost the same as those produced by irrigating every row. The configurations using four and six rows per bed (152 cm) produced yields equal to two rows per bed. However, the four- and six-row configurations will not allow mechanical cultivation if required for the weeds [Raney and Scharplaz, 1975]. Various planting configurations are used on beds for soybeans. Bed-planting enhances surface drainage.

There are many different types of furrow openers and equipment for bedding. A consideration in using furrow irrigation with soybeans is that ridges of soil should not be made between the rows that would prevent a combine header from operating as close to the ground as possible.

A slope is required to move water across the field. To avoid excessive erosion, furrow slopes generally should not exceed 2 percent. The most desirable furrow slopes would be 0.2 to 0.5 percent. Some cross or side slope is allowable, generally not more than twice the forward slope.

For best efficiency with furrow irrigation, the largest practical stream should be used to force the water across the field. At the same time, the flowing water should not cause excessive erosion. The maximum stream is often based on three limitations: (1) soil intake rate; (2) maximum nonerosive stream flow; and (3) furrow capacity.

The maximum allowable length of a run on a particular soil and slope is the distance that the greatest allowable furrow stream will flow and still give reasonably uniform distribution along the furrow. The primary factors determining the proper length of the run are the type of soil, the slope, and the erosion and drainage hazards.

Runoff must occur at the lower end of the field to ensure uniform water application there. The runoff can be controlled by decreasing the size of the stream in the furrow after the initial stream reaches the lower end of the field. This is often referred to as the "cutback" method. It requires additional labor to make the change in stream size. Using tailwater recovery (runoff water from the lower end of field) and reuse systems has become common in the Great Plains. Runoff water is collected at the lower end of the field, conveyed to a sump or pit, and then pumped back to the upper end of the field for reuse on the same field or on another one.

BORDER SYSTEMS. The border method of irrigation confines water between small, parallel ridges of soil—the borders, dikes, or levees—which guide a sheet of flowing water down the slope. The area between the ridges is often called a border or border strip. Border irrigation is commonly used to irrigate alfalfa, pastures, and fields of small grain; but it could be adapted in most cases for soybeans. Typical border widths range from 6 to 18 meters. The distance between dikes depends on the amount of water available and on the cross slope, if any. The borders should be as close to being level crosswise as possible. Cross slopes will cause the water to concentrate along one side of the border, creating an uneven distribution of the water. Border irrigation is commonly used when the slopes in the direction of irrigation are from 0.1 to 1.0 percent.

To design a border irrigation system involves considerations of soil type, slope, the dimensions of the borders, and the flow of the water so that the desired amount of water is applied uniformly to the entire field without waste from deep percolation or surface runoff. The hydraulics of border irrigation have been studied extensively, and considerable design information is available [Soil Conservation Service, USDA, 1974].

Border irrigation probably could be used successfully for soybean irrigation if the system is properly designed and operated. Small corrugations in the downslope direction might be useful to help the water move across the field in borders cropped with soybeans.

BASIN SYSTEMS. The basin method of irrigation has been used throughout the world for as long as irrigation has been practiced. Basin (level-basin) irrigation involves applying water to a level area of any shape surrounded by a control barrier, such as a dike. Water is applied to the basin over a short period of time and is confined until being absorbed by the soil.

The correct basin size depends on the flow rate of the water and the infiltration characteristics of the soil. Basin irrigation can be adapted to most crops and soils and to certain low-quality sources of water; but it is best adapted for soils with medium to slow intake rates and medium to high water-holding capacities. High application efficiencies can be achieved by using basins if a proper design and application amount are employed.

Furrows or beds can be used within a basin since the same elevation of water will be attained on all parts of the field. The furrows are connected at both ends of the field. Large streams of water are required so the entire basin can be covered rapidly in order to achieve uniform distribution. Stream size is a primary factor in determining basin size.

A major limitation of level-basin irrigation is that precision leveling is required in order to achieve an even distribution of the water. This has been made easier by using land-leveling equipment controlled by lasers. Basin irrigation normally requires more land leveling than other surface irrigation methods.

Erie and Dedrick [1979] provide basic design principles for basin irrigation. Four factors must be considered in such designs, the: (1) water-intake characteristics of the soil; (2) available flow rate; (3) resistance to flow caused by the crops; and (4) quantity of water to be applied. Basin sizes range from 0.02 to 16 hectares. Additional design information is available from many sources, including: Booher [1974]; the Soil Conservation Service, USDA [1974]; and Slabbers [1971].

Other Considerations with Surface Units

Surface irrigation is very versatile and can be used to irrigate a variety of crops under many conditions. A complete surface irrigation system is not purchased directly from an equipment dealer. The system must be designed for the specific site, integrating the land characteristics and the equipment necessary for water distribution. Because surface systems and the land have no uniformity, surface irrigation requires intensive management.

Land grading and shaping is important for good application efficiency and uniform water distribution. Rawitz [1973] calls land grading the basic and most important operation in the construction of a surface irrigation system. Precision leveling is required for basin irrigation, as noted. The quality of land leveling will affect efficiency. Booher [1974] and the Soil Conservation Service [1959] are among the sources of information on land preparation for surface irrigation.

Automating surface irrigation is related to concerns about limited supplies of water, labor, and energy. The automation of surface irrigation started with water control in open ditches in the middle to late 1960's [Haise and Kruse, 1969; Humpherys, 1967]. As irrigators started to use pipelines for water distribution, considerable work was done on control systems for sequencing through irrigation sets [Humpherys, 1971; Eisenhauer and Fishbach, 1978; Humpherys *et al.*, 1979]. That work continues. A recent report on automation describes equipment that will control the flow from each gate on gated pipe, rather than on a full set [Stringham and Keller, 1979]. Other work with the level-basin systems in the Southwest United States has resulted in automated efforts to control the flow into the basins [Dedrick and Erie, 1978; Erie and Dedrick, 1978].

Irrigators should continue to adopt modern surface-irrigation technology where the soils, topography, and other factors permit. Aluminum and plastic gated pipes are now used widely for water distribution, although open-ditch laterals and siphon tubes are still employed. Underground plastic pipe or lined ditches for water conveyance are desirable for improving system efficiency and reducing labor requirements. The development of automated surface systems reduces the labor requirements but increases the investment costs. A continuing advantage of surface systems is their low energy requirement.

Sprinkler Units

Many types of sprinkler systems now available would be suitable for use on soybeans. Only general descriptions of the major system types will be given here. The application efficiencies of sprinkler systems tend to be higher than those of surface systems, partly because some of the management factors are built into sprinkler systems. However, the efficiency of sprinkler systems varies greatly. Efficiency is affected by evaporation during application, evaporation from the soil surface, runoff due to high application rates, nonuniform distribution, and the amount of water being applied.

Sprinkler irrigation can be used where surface irrigation is inefficient or impossible because of excessive slopes, irregular topography, erosive soil, unfavorable intake rates and soil profiles, or combinations of these factors. Any sprinkler system must be designed to fit the conditions under which it will be used. The major factors to consider are: (1) application rate; (2) application amount; (3) system capacity; (4) uniformity of application; (5) water losses; and (6) economical pipe size. Several sources provide design and descriptive material on sprinkler systems. These include Pair [1975], Christiansen and Davis [1967], and Pair [1968].

Sprinkler irrigation can be adapted to most sites, but careful consideration must be given to system selection. Sprinkler systems require a relatively high initial investment and have an additional energy requirement in order to provide the pressure. Usually, little or no land leveling is needed. On sandy soils with high intake rates or on nonuniform soils with varying intake rates, water applied by a properly designed system is distributed more uniformly than by other methods. Light and frequent applications can be made efficiently on shallow or sandy soils.

SYSTEMS MOVED BY HAND. These systems consist of aluminum pipe laterals with

sprinklers. The laterals are set in one location and allowed to operate until the desired application has been made. Then, the pipe must be moved laterally 15 to 20 meters for the next set. The investment for such a system is relatively low, but the labor requirement is relatively high. Systems moved by hand can be used on odd-shaped fields and on rolling topography. The laterals are normally pipe that is 10 cm in diameter, although pipe with a diameter of 5 cm or 7.5 cm could be used in small systems. Hand systems can utilize small sprinklers or the large-volume, gun-type sprinklers. The labor requirement is high for both types. The operating pressures of the system will normally be 310 to 415 kiloPascals (kPa)[1], or 45 to 60 pounds per square inch.

TOW-LINE SYSTEMS. These are sometimes referred to as end-tow or tractor-tow systems. The tow-line system is normally a sprinkler lateral made of aluminum pipe 10 cm in diameter. The lateral is equipped with skids under the pipe joints and outriggers to keep the sprinklers upright. The lateral is generally 400 meters long, with mainline pipe running through the middle of a field that is 800 meters wide. The lateral is towed by a tractor back and forth across the centerline of the field. The distance between lateral settings is normally 18 to 20 meters. The path in which the sprinkler is towed will damage 2 or 3 rows of a crop. Tow-line systems work best in rectangular-shaped fields. The cost of a tow-line will be greater than for a system moved by hand, but will have a lower labor requirement. Near [1975] describes tow-line systems in detail.

SIDE-ROLL SYSTEMS. The aluminum lateral line is mounted on wheels. In many systems, the pipe serves as the axle for the wheels. The system is operated like one moved by hand, except that the system moves between lateral sets on wheels. The spacing for the lateral set normally will be 18 to 25 meters. The main line pipe is run along the edge of the field and connected to the lateral with a short section of flexible hose. Most side-roll systems use an air-cooled, gasoline engine located near the center of the lateral for moving power. The length of the lateral normally is 400 meters. Side-roll systems must be used on rectangular fields. They are difficult to use on sharply undulating fields. The cost of the side-roll system is greater than that of the hand-move and tow-line systems. The labor requirement will be slightly less than for a tow-line setup. Williams [1975] discusses the use of side-roll systems.

TRAVELING, BIG-GUN SYSTEMS. The traveling gun consist of a single high-capacity nozzle mounted on a 3- to 4-wheel trailer. A 200-meter, flexible hose is used to supply water to the system. The system has a cable that is 500 meters long, stretched across the field and anchored at the other end to begin a set. An internal-combustion engine or a water turbine on the trailer operates a cable winch. As the winch turns, the trailer moves across the field—pulling the flexible hose which is connected to a main line in the center of the field. Some traveling, big-gun systems use semirigid tubing to deliver water and to pull a big-gun sprinkler across the field. A common area per set for a 400-meter travel path will be approximately 4 hectares. To achieve relatively good water distribution, the travel lanes should be spaced at 60 to 65 percent of the wetted diameter at the operating pressure reported by the sprinkler manufacturer. The sprinklers on the traveling big-gun units normally require operating pressures of 550 to 690 kPa with the corresponding pump pressure at 690 to 860 kiloPascals. This high pressure requirement increases the pumping horsepower needed and the fuel consumption. The system can be adapted to various crop heights, odd-shaped fields, and irregular topography. The application rates are relatively high. The initial investment is greater than for the tow-line and side-roll systems. The labor requirement is likely to be equal to or greater than that for a tow-line system. Kruse [1975] presents the characteristics of the traveling big-gun system.

CENTER-PIVOT SYSTEMS. A center-pivot system is a self-propelled, continuously moving sprinkler lateral that rotates around a center pivot point, irrigating a circular area of approximately 52 to 54 ha out of 64 ha in a field 805 meters square. The lateral is supported by towers spaced 30 to 60 meters apart, utilizing cable or truss supports. The towers can be fitted with steel wheels or wheels with rubber tires. Center-pivot systems can be propelled by electric- , oil- , or water-driven systems. Oil- and electric-drive systems have a higher initial investment than water-driven ones but have the capability of

[1]One kiloPascal (kPa) equals 6.894 pounds per square inch. A Pascal is measured in Newtons per square meter.

reversing instantly. Also, they can be moved forward or backward without applying water. Center-pivots can operate on rolling topography and have several rotation speeds allowing a variation in application amounts. The operating pressures for impact sprinkler systems are 380 to 550 kiloPascals. The systems utilizing spray jet-type nozzles operate at pressures of 170 to 275 kilo-Pascals. Application rates with the spray-jet nozzle systems are high. Caution should be employed in using these systems on soils other than sandy ones. The investment cost will be greater than with most other systems, but the labor requirement will be lower. Circular or rectangular fields are required, although short systems can be employed on irregularly shaped fields by using multiple pivot points and moving the system from point to point. Surface drainage must be provided with any sprinkler system; but this is often not considered with center pivots, leading to problems with surface drainage. Bergsrud [1979] provides an excellent description of the various options available on center-pivots as well as general guidelines for system selection. Pair [1975a] presents a good discussion of the design considerations that affect water distribution with center-pivot systems.

OTHER SPRINKLER SYSTEMS. The newest innovation utilizing the center-pivot technology is the continuous lateral-movement system. These systems use a lateral similar to a center-pivot, but the lateral moves in a straight line rather than in a circle. The systems now available commercially are supplied with water from a pump, mounted on the system, that pumps water from an open ditch. Systems probably will be available in the near future that will use a flexible hose to supply the water. Although not commonly used, boom-type sprinklers are available that could be employed for soybean irrigation—utilizing a rotating-boom system, which must be moved, or a system that is moved mechanically. In addition, a boom mounted on a crawler tractor equipped with a pump and moved along an open water-supply ditch has been used.

OTHER IRRIGATION METHODS

Drip irrigation is being practiced in many of the arid areas of the world where water conservation is critical. Drip irrigation is the frequent, slow application of water—usually with plastic pipelines and emitters or drip irrigation tubing. Currently, the high initial cost of drip irrigation equipment for field crops is likely to preclude its use for most soybean production.

Subsurface irrigation (controlling the water table by using an underground distribution system) also probably will not come into common use for soybean production.

DRAINAGE

For optimum crop production, adequate drainage facilities are as important as irrigation itself [Joseph *et al.*, 1970]. Both surface and subsurface drainage must be controlled adequately. Only surface drainage may be necessary in many areas. Land shaping and leveling provides for the distribution of irrigation water and for surface drainage, too. Drainage is one of the most critical aspects on which long-term agricultural production under irrigation depends.

The importance of drainage is emphasized, but the details of drainage design and practice are not included here. For such information, consult the technical literature and design guides, such as those issued by the Bureau of Reclamation [1978] and the Soil Conservation Service [1973]; also, by van Schilfgaarde [1974]. The drainage system should be planned at the same time as the irrigation system.

SYSTEM EVALUATION AND MANAGEMENT

Most soybean irrigation is done with existing irrigation systems. These systems may or may not be well designed and properly used. Merriam and Keller [1978] have provided an excellent resource for the evaluation of irrigation systems in their recent publication "Farm Irrigation System Evaluation: A Guide for Management." The techniques for system evaluation they describe are designed for evaluating actual operation and management; also, for determining the potential for a more economical and efficient operation. Such evaluations are necessary when deciding whether to continue existing practices or to improve them. Better management of water on the farm may conserve water, labor, and soil and may also increase crop yields.

The best possibilities for saving water and labor usually exist when the water supply is flexible in terms of frequency, rate, and duration. Flexibility in frequency means that the water is available on or near the day when it is needed to match the moisture demands of the crop. Flexibility in rate means that the rate of supply can be changed to match different sizes of fields and cutback streams and can also accommodate varied rates of infiltration, thus smoothing out the irrigator's workload. Flexibility in duration means that the water can be turned off as soon as the soil-moisture

deficiency has been met and requirements for leaching have been satisfied. Such flexibility is necessary in order to achieve an efficient use of water.

SUMMARY

Most irrigation systems, both surface and sprinkler, can be used or adapted for growing soybeans under irrigation. Success depends on the proper selection, design, and operation of the irrigation system. Some of the factors that must be considered in the selection and design of a system are the: (1) source, amount, and quality of the water supply; (2) topography; (3) soil characteristics; (4) cropping program; (5) labor available; and (6) investment required. The system must be selected and designed to fit the site where it will be used. Land shaping and proper drainage are essential parts of the planning and development. Evaluating the actual system's operation and management can help determine the potential for a more economical and efficient operation.

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Salinity Management for Soybean Production

J. VAN SCHILFGAARDE

ABSTRACT: Soybeans show a wide variation in salt tolerance. Some commercial varieties are moderately tolerant. The tolerant varieties tend to exclude chlorine (Cl) from the leaves. No clear evidence has been reported of specific sensitivity to sodium. In contrast to some other species, salinity causes an excessive accumulation of Pi, inorganic phosphorus energy source, as orthophosphate in the leaves even when Pi levels in the root media are relatively low. The range in genetic variability permits the selection of tolerant varieties where salinity is a problem and offers promise for combining further salt tolerance with other desirable traits in future breeding programs.

For general use, salt tolerance is most readily expressed in terms of two parameters: the threshold salinity, below which there is no yield depression; and the slope of the yield-depression line beyond the threshold. The U.S. Salinity Laboratory has long advocated that salinity be measured according to electrical conductivity (EC) expressed in units of the saturation extract. The units are deciSiemens per meter (dS/m). A Siemen equals ohms + meter.

Salinity management, always an integral part of water management under irrigation, requires that accumulating salts be removed through drainage. All irrigation water contains some salt, but the water that is evapotranspired does not. The fraction of the applied water that percolates below the root zone is called the leaching fraction (L). The average, steady-state fraction that must percolate below the root zone to avoid excessive salt buildup is the leaching requirement (L_r). As a good first approximation, these water fractions are inversely proportional to their salt concentrations or, conveniently, their electrical conductivity. Thus, we may write:

$$L = \sigma_i/\sigma_d \quad \text{or} \quad L_r = \sigma_i/\sigma_d^*.$$

The salinity of the drainage water (σ_d), depends on the leaching fraction obtained. L_r is determined from the permissible drainage water salinity (σ_d^*). Of the various schemes for estimating L_r, a simple yet effective one is based on an approximate root zone average, using the equation:

$$\sigma_d^* + 5\,\bar{\sigma}_e - \sigma_i,$$

where $\bar{\sigma}_e$ is the average root zone saturated extract EC and σ_i the EC of the irrigation water. The threshold salinity for the crop considered is then used for σ_e. This method yields lower values for L_r than ones often recommended in the past.

L_r only provides a lower limit for the amount of leaching water needed—and, hence, of irrigation water. Good water management requires timely and uniform applications of the proper amounts of water, including a provision for leaching and for sufficient drainage. The *minimum* drainage requirement is determined by L_r; the *actual* drainage requirement, by the irrigation system and its management. Only through properly managed and adequately integrated irrigation and drainage systems can salinity problems be kept under control without excessive costs in terms of natural and/or financial resources. Frequently, leaky or poorly operated water distribution systems dominate in causing salinity problems.

SALINITY IS AN EVER-PRESENT CONCERN when crops are grown under irrigation. Salt introduced with the irrigation water must be removed in order to prevent a buildup

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in the soil solution to levels that will harm the crop. Although the mechanisms of salt tolerance by plants are not well understood, enough information is known about crop plants in general and for soybeans [*Glycine max* (L.) Merr.] in particular to develop general recommendations for water management. Following a brief discussion of plant tolerance, such management strategies will be described.

SOYBEAN TOLERANCE TO SALINITY

The tolerance of a crop to salt is expressed most effectively as the yield expected for a given level of soluble salts in the soil solution in relation to the yield in the absence of salinity [Bernstein, 1974]. Such relative tolerances reflect the expected response of crops grown under recommended, normal cultural practices. In the literature, one finds data obtained through numerous experimental techniques. Although these data often are valuable for the study of specific effects, some common standard must be used for comparison.

Maas and Hoffman [1977] summarized the available literature, expressing their conclusions in terms of the threshold below which crop yields were not depressed by salinity and a factor for the rate of yield reduction per unit of increase in salinity above the threshold. Following the practice of the staff at the U.S. Salinity Laboratory [1954], the unit used was the electrical conductivity of the saturation extract ($^{\sigma}e$) in deciSiemens per meter. For soybeans, they reported a threshold of 5 dS/m and a slope of 20 percent yield reduction per deciSiemens per meter. These values, while not directly comparable, seem to agree with the tolerances reported by others [Lavado, 1973; Sepaskhah, 1977; Nukaya *et al.*, 1977], although Slama and Bouaziz [1978] found a substantially greater sensitivity. Qualitatively, soybeans are moderately tolerant to salt, although the sensitivity above the threshold is higher than that of many other crops classed as moderately tolerant.

As a first approximation, crop plants respond to salinity as a function of the osmotic potential of the soil solution without regard to ionic species. Specific ion effects do occur, however, and adverse effects created by excessive levels of Na and Cl have been noted [Bernstein, 1974]. We shall come back later to ion toxicity in soybeans.

Maas and Nieman [1978] reviewed the physiological response of plants to salinity. One way of explaining plant response is the concept of total stress. A more satisfying hypothesis is based on bioenergetics. All plant growth processes require energy. This energy, initially derived from the sun, is trapped, transferred, and used through a complex set of reactions. A key link in these reactions is the adenosine phosphate system. Orthophosphate is combined with adenosine diphosphate (ADP) to form adenosine triphosphate (ATP), storing energy in the process. The ATP is able to transfer energy from the point of entrapment to the point of need within the plant, where the energy is reduced again to ADP or AMP (adenosine monophosphate) as work is performed. The intricate balance maintained within the various organs of the plant (homeostasis), thus, is largely regulated by the energy balance reflected by the ratios between the amounts of adenosine phosphates present, a relation that can be expressed in terms of the adeny-late energy charge (AEC) according to the following equation in which the brackets indicate molar concentrations:

$$\mathrm{AEC} = \frac{[\mathrm{ATP} + 1/2[\mathrm{ADP}]]}{[\mathrm{ATP}] + [\mathrm{ADP}] + [\mathrm{AMP}]}.$$

When plants are exposed to stress from any cause, they react in appropriate ways in order to maintain homeostasis. The response requires energy; as a consequence, less energy is available for growth. Therefore, one would expect the effects of salinity—and of phosphorus nutrition—to be reflected in the adenylate energy change. This has now been demonstrated [Nieman and Clark, 1976; and Nieman, unpublished].

One of the important energy-consuming processes related to salinity is the adjustment of the osmotic potential within plant organs so that turgor is maintained and growth is not impeded. This process involves the selective transport of ions and the production of organic osmotica (soluble organic compounds).

Probably because of the homogeneous genetic base of most varieties of cultivated species, the salt tolerance of varieties within species is often given as relatively uniform [Bernstein, 1974]. In fact, Abel and MacKenzie [1964] found that of 6 soybean varieties, 2 were relatively salt-tolerant, 2 were intermediate, and 2 were quite sensitive. Lee was among the tolerant varieties; Jackson, among the sensitive ones. The tolerance values of Maas and Hoffman [1977] compare with those for Lee soybeans.

In follow-up work, Abel [1969] determined that tolerance was closely related to chloride accumulation in the leaves and that this accumulation seemed to be controlled by a single gene, with the gene for chloride exclusion (tolerance) being dominant. Slama and Bouaziz [1978], on the other hand, implied that soybeans are

sensitive to sodium. In a field test with 2 varieties, they found that both were quite sensitive, with Amsoy being even less tolerant to salt than Flora. These investigators used NaCl to salinize the irrigation water applied by sprinkling. Curiously, they reported high accumulations of sodium in the roots, but low levels in other tissues; they did not report the chlorine levels. These results indicate that soybeans are one of the few herbaceous plants exhibiting specific ion toxicities.

Another indication of the effect of salinity on metabolism is the level of orthophosphate (Pi) in photosynthesizing leaves. With corn (*Zea mays* L.), a low concentration—0.2 millimoles (mM)—of Pi in the saline nutrient solution (-4 bars) reduced the level of Pi in the leaves compared to a nonsaline solution and with it the level of ATP and the AEC, thus indicating a deficiency of Pi for phosphorylation [Nieman and Clark, 1976]. A similar reduction was found for tomatoes (*Lycopersicon esculentum* Mill), kidney beans (*Phaseolus vulgaris* L.), safflower (*Canthamus tinctorius* L.), and mustard (*Brassica* sp.). But with soybeans, this level of Pi in solution (0.2 mM) caused a lethal level of accumulation of Pi in the leaves [Nieman, unpublished]. The same lethal effect was not obtained with corn until the Pi concentration was raised to 2 millimoles. Soybean leaves showed increased concentrations with only 0.02 mM in the solution. Thus, a definite interaction occurs between salinity and P nutrition in a number of crops. Soybeans are especially sensitive to Pi.

To put these data in perspective, one should note that a concentration of 0.02 mM of Pi is very low for a nutrient solution, but still high compared to the level of orthophosphate usually found in soil solutions. Reisenauer, as quoted by Rhoades and Bernstein [1971], found that the soil solution for 73 percent of 149 soil samples contained less than 0.15 milligrams per liter of phosphorus as PO_4 (approximately 0.0015 millimoles).

In summary, soybean varieties differ widely in their salt tolerance. Some commercial varieties are moderately tolerant. The tolerant varieties tend to exclude Cl from the leaves. In contrast to some other species, soybeans are sensitive to Pi in the nutrient solution and tend to accumulate lethal levels of Pi in the leaves, even when Pi levels in the root medium are low. No clear evidence has been reported of specific sensitivity to sodium.

WATER MANAGEMENT FOR SALINITY CONTROL

Irrigation water contains salt; water that is evapotranspired does not. Thus, unless there is provision for drainage, the salinity in the soil solution continues to increase. The fraction of the applied water (irrigation plus rainfall) that percolates through the soil beyond the root zone is called the leaching fraction (L). When a quasi-steady state prevails and if the assumptions are made that the amount of salt taken up by the crop is negligible and that there are no chemical reactions, then L can be expressed according to the following equation, in which D represents the depth of the water, C represents the salt concentration (in, say, mg/l), and the subscripts i and d represent irrigation and drainage, respectively:

$$L = D_d/D_i = C_i/C_d.$$

When, for convenience, the salt concentration is expressed in terms of electrical conductivity (σ), the expression for L becomes:

$$L = \sigma_i/\sigma_d.$$

To avoid a crop-yield reduction, the electrolyte concentration of the soil solution must be kept below a prescribed level. In concept, this is attained by providing enough drainage so that σ_d does not exceed a designated level, σ_d^*. The leaching requirement, L_r, is the leaching fraction required to keep σ_d from exceeding σ_d^*:

$$L_r = \sigma_i/\sigma_d^*.$$

The question remains: How is one to establish appropriate values for σ_d^*? To this end, I refer to the salt-tolerance lists already cited by Maas and Hoffman [1977]. Generally, these tabulations are based on experimental conditions under which the salinity throughout the root zone is nearly constant, obtained by using a high leaching fraction for σ_d^*. It has been customary to use the value of σ, expressed in terms of the saturation extract (σ_e), at which the yield is reduced 50 percent. Thus, for soybeans, $\sigma_d^* = 5 + (50/20) = 7.5$ dS/m. With an irrigation water having $\sigma_i = 2$ dS/m, one obtains $L_r = 2/7.5 = 0.27$. However, recent findings have led to the realization that this method of estimating L_r is ultraconservative [Bernstein and Francois, 1973; van Schilfgaarde *et al.* 1974].

The values shown above have given rise to a different hypothesis. As roots extract water from the soil solution, the salt concentration in the water increases as does the energy required for further water extraction. The limit beyond which roots cannot extract water may be estimated by extrapolating the (generally linear) plot of relative crop yields against salinity to the point at which yields would be depressed 100 percent. The minimum acceptable leaching fraction, L_r, is derived from this salinity at zero yield, expressed in terms of the soil solution. If the ratio between the water content in a saturation extract and at field capacity is taken as 2, then $\sigma_d^* = 2\ \sigma_{e-o}$, where σ_{e-o} is the saturation extract salinity at which the yield is zero. Using this method, σ_{e-o} = 10 dS/m for soybeans and for σ_i = 2 dS/m, L_r = 2/20 = 0.10. For most crops, the L_r determined this way is a third to a quarter of that obtained by using the older method.

The rationale behind the new method is satisfying. Good data are limited (nonexistent for soybeans), but the data available clearly indicate that the older method overestimates L_r, even if the new method may underestimate it somewhat. The compensatory factors that make the new method reasonably safe include the nonlinearity of the relation between σ and C (in terms of mass to volume) and the processes of mineral dissolution, salt precipitation, or both. These factors tend to reduce the actual soil salinity in the lower root zone compared to the value calculated with the newer method presented here.

There is a third method for estimating L_r, conceptually somewhat less satisfying, but convenient. It was developed by Rhoades [1974]. For most crops (but not soybeans), the Rhoades method gives an estimate of L_r that is somewhat higher than that obtained by the second method, but substantially lower than with the first. The Rhoades method tends to agree with available data better than the two other methods do. Rhoades assumed that the plant responds to the average salinity in the root zone and that this average could be estimated as L_5:

$$\bar{\sigma}_e = 0.4\ (\sigma_t + \sigma_b),$$

where σ_t and σ_b are the saturation extract conductivities at the top and bottom of the root zone. This relation leads readily to the equation:

$$\sigma_d^* = 5\ \bar{\sigma}_e - \sigma_i.$$

Using the threshold value for $\bar{\sigma}_e$, the same example yields $\bar{\sigma}$ = 5, σ_d^* = 23, and, thus, L_r = 0.09.

In addition to evaluating the relation between L_r and yield, one must also be concerned with σ_i. As mentioned, most crops have a threshold value below which salinity does not reduce the yield. With appropriate leaching, water that is relatively high in saline can be used for crops with high threshold values; if used on crops with low thresholds, a yield reduction is inevitable.

The question of an irrigation management and leaching regime is not fully resolved. Many viewpoints exist. For that reason, I presented a rather lengthy discussion. The important points are that L_r depends on both crop species and water quality and that the method for estimating L_r advocated in the past by the U.S. Salinity Laboratory [1954] is too conservative. I recommend the Rhoades method as reliable enough for routine use.

The determination of L_r is important, but it must be put in perspective. As already stated, the concept is based on steady-state conditions that are never obtained in the field. Furthermore, most irrigation methods result in a substantial lack of uniformity in the distribution of water over a field. Even if the average application meets the leaching requirement, some parts of the field will be underwatered and some overwatered. Thus, L_r should provide a valid comparison among crops and a lower limit for the amount of leaching required.

We turn now to the broader question of water management for salt control. Irrigation and drainage are the two primary components of water management. Logically, they cannot be divorced from each other. From the previous discussion on L_r, it is apparent that a downward flux must be maintained through the root zone, on the average, in order to avoid salination. The actual magnitude of this flux and of the drainage requirement would depend directly on the irrigation management. The drainage requirement, however, must also account for the influx of water from adjacent fields, canal seepage, and similar extraneous sources. Such components are often dominant, particularly in regions where irrigation practices are inefficient or where the water is distributed in leaky, unlined canals.

The design of drainage systems for irrigated land has been discussed in recent papers [van Schilfgaarde and Hoffman, 1977; van Schilfgaarde, 1979a]. Adequate drainage is mandatory if a healthy irrigation agriculture is to be maintained. Artificial drainage is expensive, however, and excessive drainage is wasteful. Sound irrigation practices—including improved water distribution networks and on-farm irrigation systems and techniques—are necessary in order

to minimize the need for drainage. A too facile "solution" would be to compensate for leaky distribution systems, spillage from lands, and low efficiency practices on the farm by intensifying drainage.

Attaining improvements in irrigation systems and their management may be difficult, especially since the immediate beneficiaries often are not evident. Although there is ample opportunity for innovative and new research, current technology provides numerous possibilities for significant improvements. The most difficult problem is not technological but institutional [van Schilfgaarde, 1979b]. Even though the problems are clearly different, this statement holds for Egypt as much as it does for California or Arizona in the United States.

The argument is often made that excessive irrigation should not be of concern because the excess water thus applied reappears further down in the system and can be reused. This view can be defended in special cases. Generally, however, overuse tends to aggravate drainage problems, increase energy consumption, reduce (even if only slightly) the amount of water available for beneficial use, and, most importantly, increase the salinity of the receiving waters. The last point has been developed in some detail by Rhoades and Suarez [1977].

As water percolates through the soil, minerals are either selectively dissolved or precipitated, depending primarily on the ionic composition and electrolyte concentration. As the electrolyte concentration of percolating waters changes from low to high, the reactions change gradually from significant dissolution to substantial precipitation. The species that dissolve or precipitate are primarily $CaCO_3$ and $CaSO_4$.

Thus, we have two choices: we can minimize the volume of leachate consistent with L_r, concentrating the salts that need disposal in the smallest possible drainage volume; or, we can collect the drainage water for reuse, choosing crops with a tolerance compatible with the water composition [Rhoades, 1977]. In practice, a combination of both approaches needs to be used for maximum benefits from the water supply. However, eliminating seepage and reducing deep percolation to the extent possible tend to optimize the system.

CONCLUDING REMARKS

Enough is known about water management for salt control to develop effective systems that make efficient use of resources. There are still many gaps in knowledge. Research is needed and opportunities exist for develing new and innovative management techniques. But the gap between what is known and what is used is just as large.

Soybean varieties with a reasonably high tolerance to salinity are available. The genetic variability within soybeans is great, so it should be possible to combine high salt tolerance with other desirable traits in future breeding programs.

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Systems of Soybean Production Including Rotations and Multiple Cropping

J.A. THOMPSON

ABSTRACT: In New South Wales, soybeans are usually grown as a full-season, single crop. Perhaps 10 percent of the area would be double-cropped after a winter cereal grain. The latter system is common in California. Reports indicate that soybeans are also double-cropped before or after winter cereals in central Kansas and following a variety of winter crops in Jordan.

Although intercropping, particularly with maize, is a common practice in humid regions, there are few references to such patterns under more arid conditions. Similarly, there is little evidence of any established rotations involving soybeans. Attempts to assess the potential of rotations in contributing to the nitrogen supply of the following crop have been conducted and are continuing.

Soybeans have a higher water requirement than other summer field crops. Varieties with a shorter growing season would reduce this requirement and would also allow them to be double-cropped as the second crop with more assurance. Unfortunately, their photoperiod sensitivity restricts the planting time and limits the manipulation of season length. Varieties with improved seedling vigor would be valued where the climate and soil conditions, or both, are unfavorable for emergence.

Soybeans are grown primarily as a full-season, single crop or under double-cropping where the growing season is long enough to allow the beans to mature. That situation is not likely to change in the foreseeable future.

MOST OF THE WORLD'S SOYBEAN PRODUCTION occurs in humid, rain-fed environments. This is reflected in the published research literature. The arid and semiarid regions of principle interest to this conference are the Middle East, Southwestern United States, and Australia. Within those regions, a rapid increase in irrigated soybean production has occurred in two areas. McClellan [1979] indicated that in California, commercial soybeans increased from 2 hectares in 1973 to 4,000 ha in 1977. In Australia's New South Wales, the irrigated area harvested has increased from about 100 ha in 1968 to 15,000 ha in 1979. Over the same period, average yields have risen from 290 to more than 2,000 kilograms per hectare. Several large commercial fields averaged 3,700 kilograms per hectare for the recently completed harvest [personal communication, R. Browne, New South Wales Department of Agriculture, 1979], a yield level indicating that a definite potential exists for irrigated soybeans in arid regions.

The definitions used here are set forth below. Unless otherwise stated, reference is made only to soybeans grown under irrigation.

SINGLE CROPPING: The production of one crop from a field in a year.

MULTIPLE CROPPING: The production of two or more crops from a field in a year.

- Sequential cropping: Growing two or more crops in sequence on the same field in a year.
- Intercropping: Growing two or more crops simultaneously on the same field.

ROTATION: The repetitive cultivation of an ordered succession of crops (or crops and fallow) on the same land.

RELAY CROPPING: The seeding of a second crop into a previously established crop, with each crop harvested separately.

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Andrews and Kassam [1976] present clear definitions of eight principal multiple-cropping patterns, and their use should be encouraged. Double-cropping is a form of sequential cropping where two successive crops are grown on the same field during the year. Rotation and relay cropping are also included in the definitions given here.

PRODUCTION SYSTEMS

Single Cropping

Soybeans usually are grown as a full-season, single crop in New South Wales. In the main cotton-growing areas, soybeans are raised as an alternate crop rather than in a set rotation. Compared to cotton, soybeans offer advantages in terms of lower input costs and fewer insect problems; also, the soil is left in a friable condition. That last aspect together with easy incorporation of minimal residue makes soybeans an ideal crop for use in situations where new irrigation layouts are being established or where old ones are upgraded [personal communication, R. Browne].

The main deterrant to soybean production is the high demand for water. Thompson [1979a] found that soybeans supplied with adequate irrigation water have a greater seasonal demand than corn, grain sorghum, or sunflowers. Thompson [1979b] also indicated that in a semiarid environment, water-use efficiency did not vary a great deal over a range of irrigation schedules—suggesting that for any reduction in water supplied, there will be a consequent reduction in seed yield.

Multiple Cropping

Although the practice of multiple cropping appears to have a long history, it has not received much research attention from agronomists until recently. Double-cropping, probably the simplest form of multiple cropping, is becoming more common.

SEQUENTIAL CROPPING. When discussing management practices in California, Beard and Knowles [1973] stated that double-cropping seemed to offer the best possibility for soybeans to succeed as a profitable crop there. McClellan [1979] indicated that most soybeans are planted as a double crop following the harvest of winter cereal grains.

In New South Wales, some 10 percent of the soybean area is double-cropped after a winter cereal, usually wheat [personal communication, R. Browne]. The longer the growing season after the harvest of the preceding crop, the higher the potential soybean yield. Using an earlier maturing variety of soybeans or an earlier winter cereal, such as barley, increases the chances of a successful soybean harvest.

Soybeans can be a successfully double-cropped following wheat in central Kansas [Gomm *et al.*, 1976]. Aerial seeding into the wheat crop and keeping the soil moist with irrigation until the soybeans are established have been proposed as ways of planting earlier.

Nasr [1976] reviewed multiple cropping in Egypt, Iran, Iraq, Saudi Arabia, Syria, Jordan, and Lebanon. He mentions soybeans only when discussing Jordan and Lebanon. They are double-cropped with a variety of winter crops in Jordan. Nasr's own research, based at the American University of Beirut in Lebanon, established that soybeans and corn silage, as well as barley and soybeans, would be successful in a double-cropping system.

The timeliness of operations is often the key to successful double-cropping, especially where the growing season is limited [Beard and Knowles, 1973; personal communication, R. Browne]. Attention to detail may need to be greater than with a full-season, single-crop system.

INTERCROPPING. This practice is found mainly in tropical regions where conditions favor rapid plant growth. However, Galal *et al.* [1976] suggested that in Egypt, soybeans can only be produced as an intercrop with maize because of the competition created by the principal summer crops, such as cotton, rice, and corn. Different cultivars of soybeans and corn and several plant populations of corn were intercropped under different patterns. Grain yields of intercropped corn were increased and soybeans decreased compared to the monocrop species as a single crop. The land-equivalent ratios varied from 122 to 131, indicating that the system has possibilities.

Rotations

Few established rotations involving soybeans exist. Since soybeans are a legume with little stubble to dispose of, though, those facts should encourage rotations with soybeans as one of the crops. Soybeans have been considered as a potential crop for rotation with rice in the irrigated areas of southern New South Wales, but success has been limited because of difficulties with establishment on the heavy clay soils and the lack of a suitable variety.

Musa and Burhan [1974] compared the performance of several forage legumes as rotational crops in the Sudan Gezira. They

concluded that when legumes, including soybeans, are cut and removed for fodder, this leaves only limited amounts of fixed nitrogen to contribute to rotational effects. The conclusion from a number of detailed studies is that soybeans, at best, can only produce enough symbiotic nitrogen to meet their own requirements. This is not surprising, considering the high protein content of the seed produced.

SYSTEM-ORIENTED PROBLEMS

Constraints on Planting Time

Lawn and Byth [1979] reviewed soybean production in Australia. They indicated several factors that may restrict the planting date when soybeans are grown either as a single crop or as a sequential crop.

Adequate moisture at seeding time is essential for uniform germination and rapid emergence. At the same time, excessive moisture and anaerobic soil conditions are quite detrimental and may cause the seed to rot in the soil. Irrigation should ensure the presence of adequate moisture; but planting seed where moisture is sufficient, especially with heavy machinery, can still be difficult under hot, arid conditions. Where furrow irrigation is practiced, planting into a dry seed bed and then irrigating can result in better emergence. The water level in the furrow must not rise above the seed in the ridge or hill; if it does, the seed may be damaged by rapid imbibition.

Soybeans are a photoperiod-sensitive crop requiring a particular day-length before they will begin to flower. In addition, a number of studies have indicated that the critical day-length for successive phases of development may be shorter than that for flowering. Such requirements are, of course, satisfied by the decreasing day-length after midsummer when soybeans are planted as a summer crop. However, adaptation problems may arise with plantings made in the winter or early spring using photo-periodically sensitive cultivars that commence pod-filling during periods of lengthening days. This can cause a complete reversal of the flowering stimulus and a reversion to vegetative growth, even after floral induction has occurred [Lawn and Byth, 1979]. Further, the work of Constable [1977] shows that each cultivar has its optimum planting date for obtaining the maximum yield.

Lawn and Byth [1979] also point out that low temperatures in the autumn can slow down seed development, reduce seed size, and delay maturity. Thus, these considerations become important in terms of utilizing late-maturing cultivars, making late plantings, or both.

Water Requirements

When soil moisture was maintained at an adequate level, soybeans used 75 percent of the corresponding pan evaporation from emergence to physiological maturity [Thompson, 1976]. This relatively high demand needs to be met, especially during flowering and pod-filling; otherwise, the yield will be substantially reduced [Brady *et al.*, 1974; Shipley and Regier, 1970; J.A. Thompson, unpublished data, 1976-1978]. The irrigation interval may be extended during the preflowering period without much of an effect on yields, but the saving in water use will be small.

Thus, soybeans not only require adequate moisture at planting time, but also need to be well supplied during an extended period covering the late flowering and pod-filling stages. There is little prospect of producing an economical crop of soybeans where irrigation is restricted, particularly under conditions of high evaporative demand.

Soybeans Before or After a Winter Crop

In most double-cropping situations, soybeans are planted after the winter crop. However, Gomm *et al.* [1976] mention that in central Kansas, some producers prefer to plant soybeans at the optimum time and then follow with wheat, because the soil is mellow and seedbed preparation is minimal following soybeans. This alternative has merit, especially where difficulties are likely to be encountered with soybean establishment. In New South Wales, there would be more time to establish the winter crop that way; and even if planting were delayed, the resultant yield reduction would not be as detrimental as with soybeans.

CURRENT RESEARCH AND DEVELOPMENTS

This section necessarily is confined to activities within the semiarid areas of Australia.

Varieties

An attempt is being made to establish soybeans as a crop on the Ord Irrigation District in the far northern part of western Australia. Although within the tropics (latitude 15° south), the climate would be classed as semiarid. Crops are irrigated about 8 times per season [personal communication, A. Garside, Western Australian Department of Agriculture, 1978-1979]. The main thrust at present is toward selecting early maturing varieties that will allow crops such as sunflowers to be double-cropped after soybeans. Trial yields in the vicinity

of 3,000 kilogram per hectare are encouraging. Commercial yields at the same level should be readily achievable once growers gain experience.

In southern New South Wales (latitude 34° to 36° south), the present commercial varieties yield well under experimental conditions, but often perform poorly in commercial situations. Varieties with more vigorous growth characteristics, particularly in the emergence and seedling stages, and that mature earlier would give farmers greater confidence. Many breeding lines are being field-tested with promising results [personal communication, D.L. Chase, New South Wales Department of Agriculture, 1978-1979]. The timely establishment of an appropriate plant stand is essential for producing an economic yield.

Intercropping

Soybeans were intercropped with corn and grain sorghum for two seasons at Breeza in northern New South Wales [personal communication, J.F. Holland and W.L. Felton, New South Wales Department of Agriculture, 1973-1975]. In the first year, two beds (6 rows) of each crop were alternated. In the second year, one bed of each crop was alternated. There was no significant response in the first year; but in the second year, the soybean yield was increased by 12 percent when the beans were intercropped with grain sorghum and by 25 percent when intercropped with corn. The land-equivalent ratios when intercropping with corn or grain sorghum were 1.2 and 1.1, respectively.

Under the large-scale, mechanized approach employed for irrigated cropping in New South Wales, the practical application of intercropping soybeans creates some problems, the most important one being the lack of a reliable herbicide that can be used for both crops. The personnel involved indicate that if the windbreak effect is the major factor responsible for soybean yield increases, planting arrangements other than those already examined may be more beneficial and more practical. They intend to investigate the matter further.

Rotations

A major experiment studying the effect of the previous crop on cotton with particular reference to nitrogen requirements is being undertaken at Narrabri in northern New South Wales [personal communication, A.B. Hearn, G.A. Constable, and J.S. Barber, Agricultural Research Station, Narrabri, 1975, 1979]. Several crops are being grown in the first year, with cotton as the test crop in the second year. The treatments of interest here are shown in the accompanying table.

Crop Sequences Under Test at Narrabri, New South Wales

First year	Second year
Cotton	Cotton
Soybeans	Cotton
Wheat/soybeans	Cotton
Fallow	Cotton

The use of two adjacent sites has allowed the harvesting of three test crops to date. The contribution from soybeans has been greater than expected. The applied nitrogen requirement for cotton following cotton of about 150 kilograms per hectare has been reduced to 80 koligrams per hectare followng soybeans [personal communication, A.B. Hearn, Commonwealth Scientific and Industrial Research Organization, 1975-1979]. Measurement of the nitrogen uptake by the cotton plant indicated that an additional 30 kilograms per hectare are taken up following soybeans. The corresponding value for the wheat/soybean treatment was 20 kilograms per hectare.

The increased cotton yield after soybeans may have been caused by some reduction in the disease level and by the earlier harvest which allowed more time for land preparation. If this work is substantiated further, soybeans may have a definite role to play in a rotation with cotton.

Irrigation Management

Research into the water requirement of soybeans under furrow irrigation in a semiarid environment has continued at Leeton. The results indicate that when the soil profile is moist at planting time, the soybeans can withstand a significant moisture stress during the preflowering period with little reduction in yield [unpublished data, J.A. Thompson, 1976-1978]. However, the crop should not be stressed after flowering commences because it is important for a full ground cover to be obtained by the end of flowering; otherwise, the potential seed yield will be reduced. Stress during flowering lowers yield because of fewer pods. Stress during pod-filling decreases yield primarily through a reduction in the weight of individual seeds. The number of seeds per pod is largely unresponsive to irrigation management.

Despite the wide range of irrigation treatments and the substantial effect of irrigation on seed yield, only a marginal

effect has been observed on the protein and oil content of the seed.

At Narrabri, the water requirements of two soybean varieties are being studied on a grey cracking clay soil [personal communication, A.B. Hearn]. A stress day has been defined, and the relationship between soil-water deficit and leaf-water potential has been examined. It appears that soybeans will be under moisture stress when 55 percent of the water-holding capacity of the current root volume has been utilized. The season was divided into 10-day intervals. On that basis, there was no correlation between stress and seed yield until the early pod-filling stage.

Two points with practical implications have emerged from the work. First, liberal irrigation early in the growing season limits the active rooting depth, necessitating more frequent irrigation during later growth stages. Second, the two varieties have shown a substantial difference in their susceptibility to moisture stress. The effect of one day's stress on one variety was 60 percent greater than on the other.

CONSTRAINTS ON EFFICIENT PRODUCTION

Under irrigation, soybeans are grown primarily as a full-season, single crop or as a double-crop where the growing season is long enough to allow the beans to mature. Within this context, there are a number of areas where further research would be beneficial. Plant breeding will have a prominent role to play.

McClellan [1979] has indicated a definite need for new varieties in California, listing characteristics that would be desirable for the double-crop system. Varieties exhibiting greater seedling vigor and earlier maturity could lead to a substantial expansion of the crop in southern New South Wales.

The relatively long growing season for soybeans makes time schedules for double-cropping difficult and contributes to the high water use of soybeans. Plant breeders, while restricted by photoperiod sensitivity, could develop varieties with a shorter flowering period and perhaps an increased rate of seed development, or both. It seems that there is also scope for selection according to ability to tolerate moisture stress, an attribute that would be beneficial in humid as well as arid environments.

A further area where an input would be worthwhile is the development of techniques for improving plant stand establishment, both where the time for seedbed preparation is usually limited (as in the double-crop situation) and where the soil characteristics are unfavorable for soybean emergence.

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Production Management Techniques for Irrigated Soybeans

W.D. McCLELLAN

ABSTRACT: Most of the important management decisions concerning irrigated soybeans should be made before the planting season begins. Varietal selection is very important. In California, the Williams variety has performed quite well at several locations, on many soil types, and under different management practices. Williams soybeans should be grown on soils containing excessive salts (>5 to 7 mmhos/cm) or excessive boron levels (>0.5 ppm). The highest yield from a commercial field in California has been 4,100 kg/ha with this variety.

Most growers in California plant soybeans as a double crop following the harvest of a winter cereal grain. After the cereal harvest, the stubble is disked and the land is prepared for a preplant irrigation. Within 7 to 14 days, after irrigation, herbicides and fertilizers are incorporated into the soil and the seedbed is prepared. All preplant-applied herbicides presently used in commercial fields have to be incorporated to a depth of 2.5 to 10 cm for maximum effectiveness. Phosphorus is the major nutrient added to California soils before planting soybeans.

Proper seedbed preparation is critical for uniform seed germination and emergence. The seed should be of good quality. The seed must be inoculated with *Rhizobium japonicum* to insure good nodulation, especially in areas where soybeans have not been grown previously. Desired plant populations should be 250,000 to 400,000 plants per hectare.

Including the preplant irrigation, soybeans require 60 to 75 cm of water (2 to 2.5 acre-feet) during the crop season. Growers have used a preplant irrigation successfully and 2 to 8 additional irrigations through the crop season. The important consideration is to be sure the plant does not experience moisture stress once pod-setting has begun.

The major soybean pests include spider mites *(Tetranychus urticae)* and lepidopterous insects. They need to be monitored and controlled if necessary. Once soybeans reach a moisture level that suitable for harvest (13 to 15 percent), the crop needs to be harvested quickly. In a dry environment, excessive shatter and drying can result in losses of yield and quality.

THE COMMERCIAL ACREAGE of irrigated soybeans in California has increased from 2 hectares in 1973 to over 10,000 ha in 1978. The majority of these soybeans have been planted from mid-June to mid-July as a double crop following the harvest of a winter cereal grain. The increased value of soybeans in recent years and the emphasis on using them in double-cropping has made soybeans a successful addition to fieldcrop rotations in California.

Soybean research has been conducted by the University of California and the U.S. Department of Agriculture periodically since 1918. Most of the early research indicated that the yields of the varieties tested were too low to be economically acceptable. With the increased market value for soybeans in the early 1970's, growers became more interested in the potential of growing this crop on a commercial basis under irrigation. Using the information developed by the University of California and the USDA, growers and Extension Service researchers began to put soybeans into the major field-crop production areas of California.

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The comments that follow reflect field research and grower experience over the last 7 to 8 years in the San Joaquin Valley of California. In that valley, the major irrigated field crops are cotton (500,000 ha), cereal grains (300,000 ha) and alfalfa (250,000 ha). Cotton is the major cash crop and is grown in rotation with winter cereals (barley or wheat) and alfalfa. Growers may also include vegetables, sorghum, dry beans, corn, and other crops in their rotation. Because of the high cost of equipment, labor, and water, growers continually need more crops to use in their rotation systems.

The following guidelines are used by growers in the San Joaquin Valley when planting soybeans as a double crop following the harvest of a winter cereal grain.

1. The management decisions made before planting soybeans in the field include:
   a. *Yield potential.* In California, the high cost of irrigation water ($50 to $150/ha for soybeans) and land make the planting of soybeans uneconomical unless the yields are at least 2,000 to 2,500 kilograms per hectare. Growers must know their yield potential when considering soybeans as a crop.
   b. *Soil types.* The soil types in the San Joaquin Valley vary greatly. The ideal soils for soybeans are the deep, well-drained sandy loams. Many areas in the San Joaquin Valley have shallow soils with an underlying hard pan. The depth of the soils, drainage, and soil types dictate the planting procedures, frequency of irrigation, and other cultural practices needed. Soybeans planted on problem soils such as alkaline soils or ones with excessive salts (>5 to 7 mmhos/cm) and high boron concentrations (>.5 to 1.5 ppm) have not been very productive. Such soils in the San Joaquin Valley have produced yields of 500 to 1,500 kilograms per hectare.
   c. *Weed control.* This can be successful in soybeans if the grower knows his weed problems before planting the crop and if the cultural and chemical tools he has available are effective against those weeds. Soybeans should not be planted in fields with a history of hard-to-control weeds—especially perennial weeds such as johnsongrass, nutsedge, and others.
   d. *Soybean varieties.* The variety to plant probably is the most critical decision the grower makes once he has selected the field. Most varieties examined by researchers in the 1950's and 1960's tended to shatter excessively and to have very poor yields. Based on variety tests and grower experiences in the San Joaquin Valley since 1973, the main variety used in commercial production has been Williams (maturity group III). When Williams is planted as a double crop after the harvest of a winter cereal, the soybeans reach maturity 125 to 130 days after planting, yield well, do not shatter, and perform quite well on several different soil types and under various management techniques.

      The highest yield with Williams from a commercial field in California has been 4,100 kilograms per hectare. Williams has been very consistent in

Table 1. Yields and Seed Quality, Soybean Varieties Planted in Mid-June as a Double Crop following Barley, San Joaquin Valley, California, 1976-1978

	Yield[a] (kg/ha)			Percent oil[b]		Seed size (g/100 seed)
Variety	1976	1977	1978	1976	1978	1976
Amsoy 71 . . .	2,900	2,862	3,982	20.5	19.2	19.8
Beeson	2,356	2,435	...	18.6	...	21.1
Calland . . .	2,785	3,689	4,175	18.5	18.4	22.0
Columbus . . .	2,571	3,182	4,485	19.1	18.8	15.5
McKoy 1100 . .	2,783	3,345	3,206	19.5	19.9	19.6
Wells	1,781	2,924	...	18.8	...	17.0
Williams . . .	3,336	3,442	4,013	18.3	18.7	20.8

[a]Row spacing: 1976 and 1977, 96 cm; 1978, 48 cm. Yield adjusted to 13 percent moisture.
[b]By NMR analysis.

Table 2. Soybean Yields Obtained by Five Growers with Williams Soybeans as a Double Crop following barley or wheat in the San Joaquin Valley, California 1975-1978

Grower and location	Year	Hectares	Row width (cm)	Irrigation method	Yields (kg/ha)
A (Visalia). . .	1975	12	100	Flood	2,594
	1976	12	100	Flood	2,322
B (Dinuba) . . .	1976	8	100	Flood	2,323
	1977	9	25 to 50	Furrow & sprinkler	2,688
	1978	9	25 to 50	Furrow & sprinkler	2,800
C (Hanford) . .	1975	15	76	Flood	2,745
	1976	86	76	Flood	2,232
	1978	90	4 rows, 18 cm, on 100-cm beds	Furrow	3,024
D (Hanford) . .	1975	7	25	Flood	3,524
	1976	59	25	Flood	3,079
	1978	16	18	Flood	3,358
E (Tulare) . . .	1975	3	36 to 66	Flood	3,422
	1976	13	36 to 66	Flood	3,105
	1977	16	36 to 66	Flood	2,845

[a]Williams was planted as a double crop following barley on wheat.

field use and in variety tests (Tables 1 and 2). Other varieties such as Amsoy 71 and Columbus which yield well in the variety tests have not been successful in the field. Although Williams is an acceptable variety, there is a continuing need for varieties that are better adapted to the hot, arid conditions of the San Joaquin Valley. Several varieties look extremely promising, especially Elf. It is a different plant type than Williams (Table 3). Elf, a shorter plant, matures earlier and has a shorter bloom period than Williams. Elf yields well and has excellent lodging resistance. Under natural rainfall, this determinant variety does not yield as well as the indeterminant types such as Williams, especially if a dry period occurs during and after pod set. However, Elf should do well under irrigation with proper management.

Table 3. Variety Comparison, Williams and Elf Soybeans, San Joaquin Valley, California, 1978[a]

	Williams	Elf
Plant type	Indeterminate	Determinate
Days to maturity	125 to 130	110 to 115
Flowering period (days) . .	30 to 40	20 to 25
Height (cm) . . .	112	61
Height to first pod (cm)	11.5	19.1
Lodging (0=erect; 5=down)	3	1
Yield (kg/ha) . .	4,019	4,517

[a]Planted in mid-June as part of a variety trial.

2. Once the previous decisions have been made, the grower must harvest his winter cereal crop and prepare the land for the soybeans. Many growers use early maturing barley varieties in order to plant the soybeans as early as possible. Besides barley and wheat, some growers have planted soybeans after oats and sugar beets.

3. The cereal stubble is generally disked at least twice and then prepared for a preplant irrigation. This irrigation provides moisture for germination at planting time and provides deep moisture to help supply the crop's needs throughout the season. Some growers burn the cereal stubble to ease the problem of disking in the residue. This is especially beneficial for growers with small operations who do not have the large equipment required to adequately incorporate the residue which can be 6,000 to 7,000 kilograms per hectare.

4. After 7 to 14 days (depending on the weather, soil type, and the like), the

land should be ready for working up the seedbed and applying the herbicide and fertilizers. Several herbicides have been used successfully to supress weed competition. All preplant herbicides presently used in commercial fields have to be incorporated to a depth of 2.5 to 10 cm for maximum effectiveness. Which herbicide to use depends on the type of weeds anticipated and on the succeeding crops that will be planted. Persistent herbicides such as trifluralin can create a problem if cereals are planted following the soybean the soybean harvest. The grower's knowledge of his weed problems and what his succeeding crops will be play an important role in decisions about weed control. Many growers are concerned over volunteer cereal seeds germinating and competing with the soybean seedlings. The incorporation of chloropropham preplant has provided effective control. Preplant irrigation, burning, or both can also be effective in controlling such weeds. Many growers have used combinations of herbicides very successfully to control weeds, such as: (1) trifluralin plus chloropropham (grasses, broadleaves, and cereals); (2) alachlor plus vernolate (nightshade, nutgrass, and short residual); (3) trifluralin plus vernolate (grasses, broadleaves, and nutsedge).

5. Phosphorus is the major nutrient added to the soil before planting soybeans, usually at a rate of 40-60 kg of P_2O_5 per hectare. Other nutrients may be required in some soils, but no general crop recommendation is involved.

6. Proper seedbed preparation is critical for uniform seed germination and emergence. The seedbed should be firm and smooth and should have enough moisture from the previous irrigation to establish an adequate stand of seedlings. Some growers planting soybeans for the first time have not supplied enough moisture through irrigation. Poor stands developed when the seed was planted at too shallow a depth (above the moisture) or too deep (seeds germinated but did not emerge). Timing is critical and the time between the irrigation, seedbed preparation, and planting will vary depending on the soil type and environmental conditions. Flat plantings with flood irrigation are more critical than bed planting because it is very difficult to maintain a uniform moisture level throughout the field. Dry spots often stay barren throughout the season. Flood irrigation after planting is ineffective as a means of helping seeds to germinate and obtaining a stand.

   Studies on row spacings and plant populations with the Williams variety have shown yield potentials of over 4,500 kilograms per hectare on 30-cm rows and a population of 345,000 plants per hectare when grown as a double crop after barley [McClellan, 1976]. The highest yield obtained has been 4,100 kilograms per hectare in a commercial planting. This field of Williams was planted with a grain drill (rows 18 cm apart) following the harvest of wheat. Table 2 gives the yields obtained by five growers who planted soybeans as a double crop following the harvest of barley or wheat. The planting dates ranged from June 15 to July 15. These growers used different planting, irrigation, and cultural practices. Low yields were obtained in fields with row spacings of 100 or 76 cm and low plant populations (<150,000 plants per hectare). The growers who obtained the highest yields had closer row spacings (10 to 50 cm) and higher plant populations (250,000 to 400,000 plants per hectare). In addition to having excellent plant density, these growers had few weeds. The plants did not experience moisture stress during the season.

   The seed should be of high quality with good germination. It is important for the seed to be inoculated with *Rhizobium japonicum* to ensure good germination, especially when planting in areas where soybeans have not been grown before. Various methods of applying the *Rhizobium* bacteria have been used successfully.

7. Including the preplant irrigation, soybeans require 60 to 70 cm of water (2 to 2.5 acre-feet) during the crop season. Growers have successfully grown soybeans using the preplant irrigation and 2 to 8 additional irrigations during the season. The important consideration is to be sure the plant does not experience moisture stress once pod-set has started.

8. Spider mites, predominately the two-spotted mite *(Tetranchus urticae)*, historically have been considered as the major pest problem for soybeans in California. The spider mites feed by sucking juices from the plants. At high populations (greater than 500 per

Table 4. Effect of Heavy Infectations of Spider Mites (>500 Mites per Leaf) on Yields and Seed Size, Williams and Classic II Soybeans, San Joaquin Valley, California, 1978

Variety	Spider mites	Yields (kg/ha)[a]	Seed size (g/100 seed)
Williams	Heavy	2,111	17.3
Williams	Light	3,258	23.0
Classic II	Heavy	1,907	15.1
Classic II	Light	3,005	21.4

[a]Adjusted to 13 percent moisture.
Source: W.D. McClellan.

leaf), the mites can cause premature defoliation and significant yield reductions (Table 4). They prefer a warm, dry climate. Mite populations can build up very rapidly with a long photoperiod. Moisture-stressed soybeans and high temperatures provide ideal conditions for disasters induced by spider mites.

Growers' fields were surveyed for mites and other insects on a weekly basis in 1975-1976. In 1975, most growers controlled mite populations by using a preventative approach—applying miticides before economically damaging levels were reached. In 1976 and 1977, growers began to utilize chemical-control methods—only as the situation warranted and based on weekly field evaluations. Of the fields surveyed, less than 25 percent were treated with a miticide. The successful use of field-survey techniques to determine the extent of infestations by mites and other insects was an effective method of minimizing the need for chemical pest-control measures. The registration of mitcides for use on soybeans is a major problem in California. Propargite has now been cleared for use on soybeans in California and has worked quite well in a monitored situation.

9. With Williams soybeans planted in mid-June, the soybeans will begin to turn yellow and lose foliage 95 to 105 days after planting. The beans are also sizing rapidly during this period. The soybeans lose moisture quickly after that time under the hot, dry conditions of the San Joaquin Valley, going from 60 percent moisture to a harvestable moisture level of 13 percent in 10 to 14 days. A harvest delay in a dry climate results in a moisture level of 6 to 10 percent, which can result in shatter problems at harvest and split seeds in the harvested grain. Harvesting at night or in the morning with some dew formation can overcome some of these problems. Harvest losses have been assessed in several California fields. In 1975-1976, harvest losses recorded in several commercial fields ranged from 69 to 650 kilograms per hectare. Harvest losses were primarily from pods set too low to the ground and uneven ground preparation. Shatter, often considered a major limiting factor in soybean production in California, was minimal with the Williams soybeans when planted in mid-June to mid-July. Harvest losses were also minimized where close row spacing, high plant populations, and flat plantings were used. As a result, the fewest pods were near the ground, allowing the cutter bar to be set close to the ground. In 1975, harvest losses averaged 455 kilograms per hectare (17 percent of the total yield) where the soybeans were planted on beds and furrow-irrigated. This compared to 280 kilograms per hectare (9.7 percent of the total yield) where the crops were planted on the flat and flood-irrigated.

Table 5. Effect of Soybean Varieties on Harvest Losses, San Joaquin Valley, California, 1978

Variety	Preharvest Losses	Gathering-unit losses			Total loss[a]
		Shatter	Stalk	Stubble	
		kilograms per hectare			
S-1492	342	326	29	11	708
AP27	3	115	25	0	143
Classic II	1	62	26	0	89
Williams	1	47	46	0	243
LSD 0.05					243

[a]The cylinder and separation losses were negligible.
Source: Data from W.D. McClellan and J. Murphy..

Table 6. Quality of Soybean Seed in Grower Fields Planted with Williams Soybeans, 1976-1978, San Joaquin Valley, California

Grower and location	Year	Seed size (g/100 seed)	Percent Oil	Percent Protein
A (Visalia)	1976	18.5	16.9	37.3
	1978	...	18.0	37.0
B (Farmersville) . . .	1976	20.8	18.3	38.2
	1977	23.8	18.6	38.8
	1978	21.2	19.6	...
C (Hanford)	1976	21.0	17.4	37.5
	1977	23.0	16.0	38.7
	1978	23.0	17.5	...
D (Tulare)	1976	19.5	18.2	36.4
	1977	...	17.0	37.1

Source: W.D. McClellan.

In 1978, a large replicated trial was conducted in a grower's field. The soybeans were planted in 4 rows on top of raised beds 100-cm wide and furrow-irrigated. The use of high populations and some new varieties kept harvest losses to a minimum (Table 5). Excessive losses occurred only with an early maturing variety (S-1492) which shattered badly before harvest (preharvest loss) and on impact with the harvester (shatter).

10. California-grown soybeans harvested at maturity (125 to 130 days after planting) have good seed size, oil and protein levels, and appearance. Soybeans not harvested until after an extended period of fog or rain have fair quality, with more splits, blemish seed coats, and overall a poorer appearance than those harvested earlier. Such soybeans are acceptable for crushing purposes but are unsuitable for use as certified seed or for sale in the edible soybean market. The seed size as well as oil, and protein contents for several growers' fields are given in Table 6. Some of the processors in the State of California have indicated that the oil or protein contents were somewhat low. With the continued introduction of varieties better adapted to California conditions, higher oil and protein contents should be obtained.

SUMMARY

Soybeans grown in irrigated areas such as San Joaquin Valley of California must be managed differently compared to other soybean-growing regions of the world. Variety selections, herbicide choices, application methods, and pest problems are only a few of the decisions that are unique in terms of irrigated soybeans. Growers in the San Joaquin Valley have not solved all of the problems. Soil difficulties, pesticide registration, inconsistent yields, and marketing methods all need further research. Very promising propects appeared with the introduction of determinate varieties such as Elf, which reach harvest maturity in 110 to 115 days and have an excellent yield potential, lodging resistance, and seed quality.

The following is an outline of one grower's crop history for 1978:

May 28 . . . . Barley harvested.
June 2 . . . . Barley stubble disked twice and land plowed. Ground surveyed and leveled.
June 5 . . . . Borders put up, followed by a 12-hour preirrigation.
June 12 . . . Herbicides (triflurlin and vernolate) incorporated and disked twice.
June 12 . . . Planted to moisture on the flat with a grain drill (rows 17 cm apart) using 156 kg of seed per hectare. Williams soybeans were used and *Rhizobium* inoculum was added to the planting seed.
June 20 . . . Full stand had emerged.
July 12 . . . Applied miticide treatment.
July 14 . . . First irrigation.
July 28 . . . Second irrigation.
August 13 . . Third irrigation.
August 38 . . Fourth irrigation.
October 15 . . Harvest, yield averaged 3,358 kilograms per hectare.

Soybean Research Under Irrigation in Northern Australia

D.F. BEECH, R.J. LAWN, AND D.E. BYTH

ABSTRACT: This report is on research into soybean adaptation and use in the low-latitude (15°39'S), monsoonal zone of northwest Australia. Irrigation is essential in this environment for high crop yields and stable agriculture. The research has involved screening of genetic material for adaptation and the development of irrigated production systems.

All lines tested were sensitive to the range of photoperiods experienced in the region, so that phenology and development change with the planting date. However, the degree of response varies among lines. A range of types suitable for different cropping strategies throughout the year has been identified.

In general, lower seed yields were obtained from later plantings at constant density, but this was alleviated by using narrow rows and high plant density. The planting date also exerts a major influence on the incidence of damage by certain insect pests.

Surface irrigation of beds 1 to 5 m wide proved to be effective and is more compatible with high-density populations than the ridge systems. Evidence suggests that very frequent irrigation is beneficial. Studies of wet soil culture are continuing.

A small commercial area was grown using cultivars. Ross and 49-38 produced yields of 2,500 kg/ha experimentally, and may be released shortly.

SOYBEAN PRODUCTION IN AUSTRALIA is restricted mainly to the subtropical areas (25° to 33°S) on the east side of the continent. Relatively limited research has been directed to low-latitude adaptation. This report is about research conducted at the Kimberley Research Station on the Ord River Scheme in northwestern Australia (15°39'S).

The region has a dry, monsoonal climate with a hot, wet season from mid-November to March and a cooler, dry season from April to November (Table 1). Over 90 percent of the total precipitation (770 mm) occurs during the wet season. The area is characterized by high temperatures and rates of evapotranspiration, high-intensity storms, and great variability in the rainfall during the wet season. Irrigation is essential to produce high crop yields and to sustain a stable agricultural system.

This research was conducted on the main soil type, Cununurra clay, which is a grey cracking, clay (40 to 60 percent) alluvium derived from calcareous rock and intermediate-to-basic igneous rock. The soil is deficient in organic carbon and nitrogen, and has very low levels of total and available phosphorus. These deficiencies can be corrected by fertilization, but the cost of fertilizer is high because of the transportation required to get it to this isolated region. Consequently, leguminous crops may be expected to achieve an important role in the agricultural system.

Various legumes have been investigated, including soybeans, peanuts, and the grams. Only soybean research is reported here.

CROP ADAPTATION TO THE REGION

A large number of soybean accessions, mainly from the United States and Africa, were evaluated between 1957 and 1960. None were successful because of their poor adaptation and shattering characteristics.

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Table 1. *Climatic Data, Kimberley Research Station, Western Australia*[a]

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Mean rainfall (mm)	192	191	117	30	9	4	4	1	2	20	67	133	770
No. of wet days	13	12.8	7.6	2.8	1.1	.3	.5	.1	.4	2.7	6.3	10	57.6
Mean max. temp. (°C)	36.1	35	35.8	35.2	32.7	30.6	30.6	32.7	35.8	38.3	38.9	37.9	34.9
Mean min. temp. (°C)	24.3	24.2	23.3	20.7	17.7	15.2	13.9	15	18.5	22.7	24.5	24.7	20.4
Evaporation (mm)	224	189	217	217	213	180	189	228	267	286	277	258	2,745
Mean daylength (hr)	13.17	12.8	12.38	11.93	11.58	11.42	11.48	11.77	12.18	12.63	13.03	13.27	

[a]Values calculated from data recorded at the Kimberley Research Station, 1946-1971. Mean rainfall data supplemented with data recorded at the Ivanhoe Station, approximately 5 miles south, for 1907-1945. Radiation data are means for 1962-1970.

Soybean research ceased until the early 1970's when further accessions bred specifically for low-latitude environments became available. Most of these were breeding lines selected at the University of Queensland by D. Byth. Research in eastern Australia has clearly demonstrated the effects of photoperiod on the phenology and growth of soybeans [Lawn and Byth, 1974]. Thus, the importance of the cultivar, planting date, and plant density are all important in attaining high seed yields [Lawn *et al.*, 1977]. Consequently, our research has been directed toward understanding the response of different soybean cultivars to the region and developing appropriate production systems.

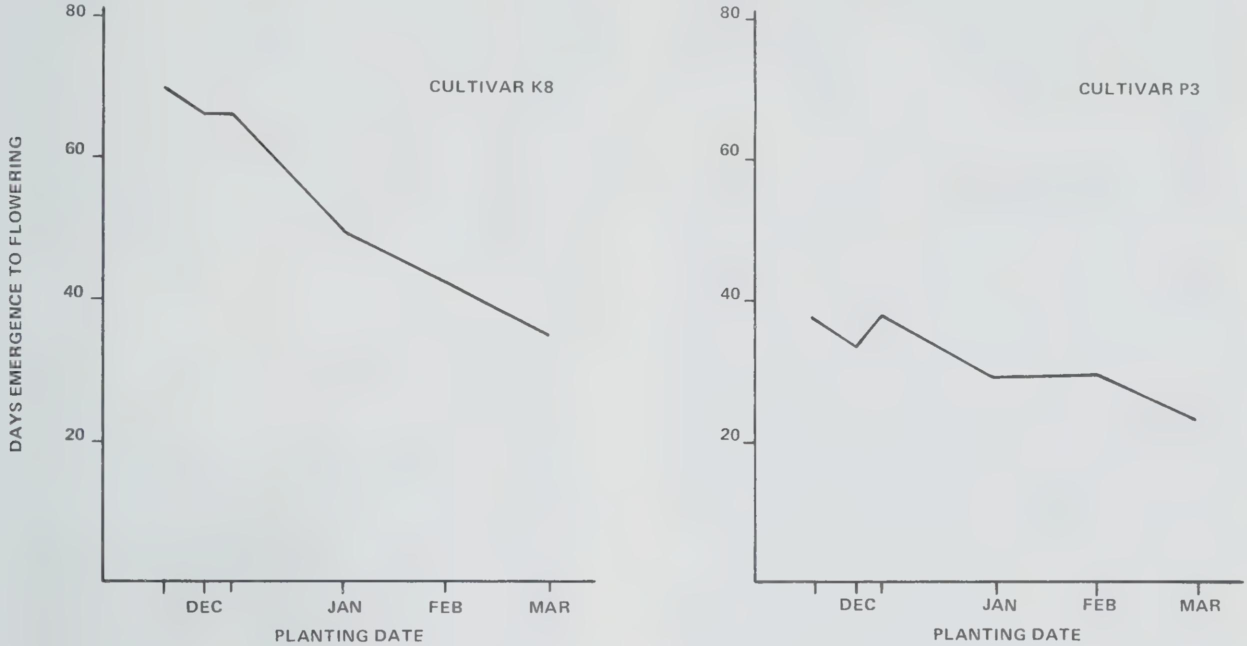

Figure 1. Effect of sowing date on days to flower of two soybean cultivars, Kimberley Research Station, Western Australia.

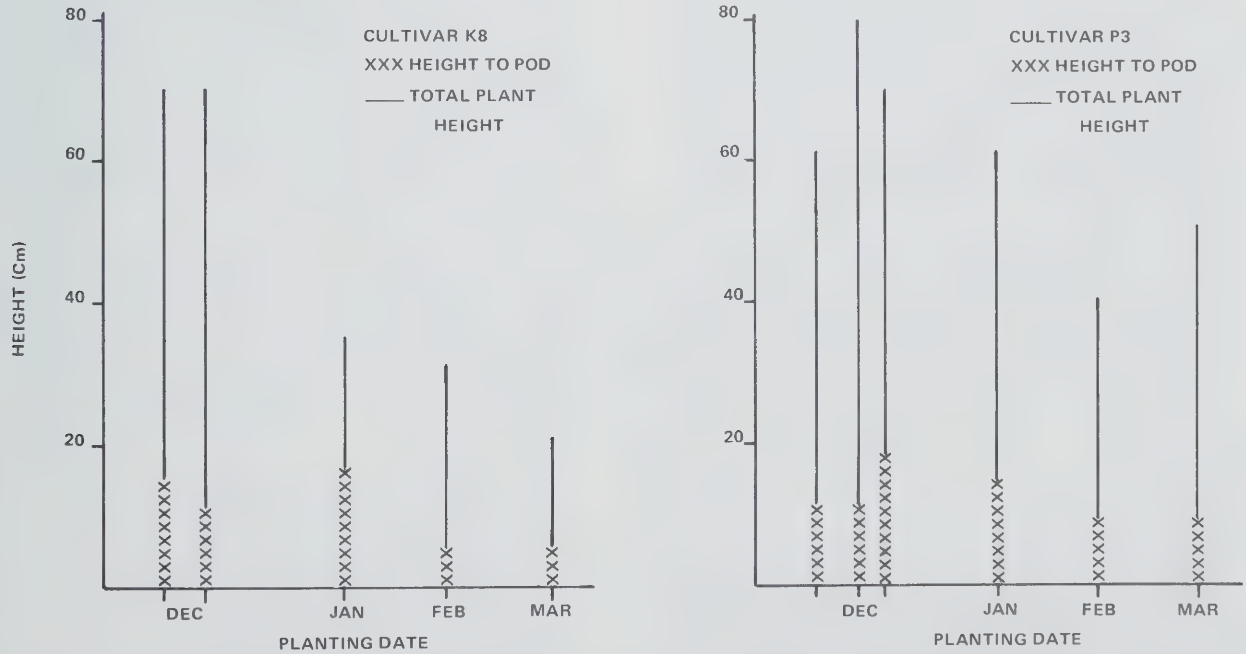

Figure 2. The effects of sowing date on days to flower, height to first pod, and total plant height of two soybean cultivars, Kimberley Research Station, Western Australia.

Two main groups of breeding lines from the University of Queensland have been evaluated. The first group (the K, V, and Cycle II lines) were selections from crosses of relatively late-maturing accessions from Africa, largely involving Mamloxi (from Nigeria) and Avoyelles (from Tanzania) and a further introgression of African germplasm. The second group of selections (the P and M lines), derived from crosses of U.S. cultivars and local breeding lines, generally mature earlier, have larger seed, and a higher percentage of oil and a lower one of protein.

All the lines have proved to be sensitive to the range of photoperiods experienced in the region (Table 1). This was shown by using serial plantings of all lines from early December to late March. The lines differed in their degree of response to the planting date. The response of K8 (Figure 1) was typical of that for the more sensitive lines, with the length of the preflowering phase decreasing sharply as the planting date was delayed.

By contrast, lines such as P3 revealed relatively small changes in the length of the preflowering phase (Figure 1), and were relatively insensitive to the range of photoperiods at the latitude (15° 39'S). These changes in phenology with genotype and planting date were accompanied by large differences in plant habit and vegetative growth (Figure 2), clearly indicating the need to adjust plant density according to planting date in order to attain the best canopy development.

As a result of these studies, we have identified lines with different phenological responses and plant habits over various planting dates in the region. Thus, genetic material is available that allows a flexible use of soybeans in irrigated cropping systems in the area—either as a crop sown early in the wet season or as one sown late in the dry season.

AGRONOMIC MANAGEMENT

In the initial studies, the soybeans were grown on ridges 75 cm apart. The planting date had a marked effect on seed yields, which declined as the planting was delayed after January. This was particularly true for the more erect, shorter-season material that was not sufficiently vegetative to occupy the inter-row space available.

The effect of greater plant density was evaluated using five lines of varying maturity and habit, four planting dates (December 21, January 19, March 15, and April 12), and four row spacings (2, 3, 4, and 5 rows per 1.5-m bed), with a constant intra-row spacing of 5 centimeters.

The results of this trial (Table 2) supported the expectations of Lawn *et al.* [1977], in that the high-density culture enabled high yields from very late plantings in the tropics. As in earlier studies in subtropical Queensland, a strong interaction existed between the planting date and plant density on line performance (Table 2). The lines differed in their response (Table 3). The highest yields were from the 4-row beds in the 2 earlier plantings and the 5-row beds in the late plantings. The yield advantage of the narrower rows was small in the earliest planting but increased with the later ones, being particularly marked with the lines that matured early.

In all subsequent studies, the soybeans were grown in a high-density, narrow-row culture. There is clear evidence that the yield decline previously experienced with late plantings can be arrested considerably by using such a cultural system, and that seed yields in excess of 4,000 kg/ha could

Table 2. Effect of Planting Date and Row Spacing on the Seed Yields from Soybeans, 1976-77 Season

Planting date	Number of rows per 1.5-meter bed				Mean for beds
	2	3	4	5	
			kg/ha		
December 21	1,112	1,126	1,210	1,183	1,158
January 18	1,188	1,623	1,758	1,653	1,556
March 15	1,421	1,809	2,050	2,132	1,853
April 12	1,029	1,466	1,639	1,674	1,452
Mean for planting dates	1,188	1,506	1,664	1,660	1,504

Table 3. Effect of Cultivar and Planting Date on the Seed Yields from Soybeans, 1976-77 Season

Cultivar	Date planted: December 21	January 15	March 15	April 12	Mean for planting dates
	kg/ha				
49-10	801	1,474	1,997	1,784	1,514
P45	834	884	1,738	1,416	1,218
K123	1,615	2,001	1,991	1,415	1,756
V15	1,694	2,030	1,445	1,063	1,561
Ross	842	1,390	2,084	1,582	1,475
Mean for cultivars	1,158	1,556	1,853	1,452	1,505

be obtained experimentally in the region using a wide range of planting dates.

MANAGEMENT ASPECTS

Irrigation Methods

All experimentation used surface irrigation. Generally, that included up to 16 applications of water totaling 600 to 700cm, depending on the crop duration and timing. Surface irrigation requires an elevated soil surface. Considerable research work has compared the effectiveness of planting on ridges 75cm apart versus beds 1.5m wide for a number of planting dates and cultivars of different maturities.

Bed and ridge culture were equally effective for the cultivar lines that matured late in which branching allowed utilization of the wide inter-row spacing. However, bed culture is obligatory for short-duration crops (late plantings or lines that mature early) because that culture allows the row widths to be adjusted in order to produce the best canopies of compact, nonbranching plants.

On the soils in the experiments, water penetration across the 1.5-m bed was adequate, but penetration could be a problem with other soil types and a different topography. Bed construction involves an extra cultural operation before planting, but seems to be justified in that it allows an adjustment of row widths and plant density for the combination of planting date and cultivar that have been selected.

Studies of soybean culture elsewhere in Australia [unpublished data, M. Hunter, University of Queensland, 1978; and unpublished data, K. Nathanson *et al.*, CSIRO, St. Lucia, Queensland, 1979] showed clearly that soybeans respond well to continuously wet soil conditions involving a fixed water table. Such circumstances produced greater shoot and root development, increased nodulation, and sustained N-fixation during the seed-filling period. Field studies in the Ord River Scheme [unpublished data, A.L. Garside *et al.*, Department of Agriculture, Kununurra, Western Australia, 1979] have confirmed the benefits associated with very frequent irrigation. Investigations continue on the application of a wet-soil culture for soybeans. There is now clear evidence for soybeans that the soil-plant-water relationship is a critical factor in the adaptation of soybeans to tropical environments, exerting a strong influence on plant growth and development.

Pest Incidence and Control

The competition by weeds in soybeans can be serious in the Australian environment described earlier, both during crop establishment and the advanced growth stages. The general practice is to incorporate the herbicide trifluralin at the rate of 2 kg a.i./ha before planting. This has provided good control of grasses and of some broadleaf weeds; but there was no control of certain broadleaf weeds such as *Sesbania* sp., *Abelmoschus ficulae*, and *Phillanthus* sp., which had to be removed by hand in the experiments. Such weeds create serious competition with the crop; so for larger areas, chemical control using Basagran at 3/4 kg a.i./ha at three weeks after planting was satisfactory. Higher rates depressed plant height and grain yields, although the oil content was affected only slightly.

Insects

Under the high-temperature conditions of the region, insect populations can develop rapidly on irrigated crops. Despite excellent plant performance, a cotton industry was aborted in the 1970's largely because the massive insect problems could not be solved. Consequently, a close study was made of the

insect populations in the soybean experimental areas.

Peak populations of different insects occur at various times of the year. The major insect pest, a stem borer (*Zygrita diva*) for which the usual native host is *Sesbania* sp., attains peak infestation in up to 90 percent of soybean plants in the premonsoon period in December or before. With later plantings, there is progressively less infestation, ranging to near zero for March plantings. However, such late plantings conflict with the use of a double-crop rotation system. Satisfactory control can be obtained with chlorpyrifos at 1.7 kg a.i./ha [Wood, 1976], but numerous applications are necessary and this presents serious ecological and economic problems.

Various sucking bugs (*Nezara viridula, Piezodorus hybneri,* and *Riportes serripes*) generally have achieved a peak infestation by the end of the rainy season. The number of green vegetable bugs was reduced drastically following the release of a parasite (*Trissolcus basalis*) by the Western Australian Department of Agriculture [Personal communication, G. Strickland, Department of Agriculture, Kununurra, West Australia, 1979].

CURRENT SITUATION

Research suggests that grain yields in excess of 4,000 kg/ha are obtainable [unpublished data, D.F. Beech, CSIRO, St. Lucia, Queensland, 1977; and unpublished data, A.L. Garside, Department of Agriculture, Western Australia, 1979]. This has led to commercial interest in soybeans as a crop for the Ord River Irrigation Area. The soybean cultivar Ross and line 49-38 were released initially. They are now being grown commercially on a small scale. Seed yields of up to 2,500 kg/ha have been obtained.

Two higher-yielding cultivars will be released before the end of 1979—one maturing earlier than 49-38 and one maturing later than Ross. The earlier cultivar will be mature soon enough to permit dry-season sunflowers to be planted at their optimum time.

A program of evaluation on breeding lines and accessions is in progress. This involves an in-depth study of plant-water relationships under a number of methods for irrigated culture.

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Effect of Planting Date on Soybean Development and Production Under Irrigation in Southern Spain

Mª. JESÚS GRANDE AND A. BORRERO

ABSTRACT: The response is reported of soybean cultivars grown under irrigation in southern Spain. The cultivars were planted over a series of dates during two consecutive seasons in randomized plots at La Rinconada, Sevilla (37° 30' north latitude). For all cultivars, each plant-development phase through flowering was extended as the hours of daylight increased and the temperatures became cooler. Yields decreased when the plantings were made in early April. Planting dates in May and early June appeared to be optimum, although seasonal and cultivar differences occurred. Generally, there was a decrease in yields when planting occurred in late July because of the small plant size and the low position of the first pod.

THE OBJECT OF THIS REPORT is to present information about the behavior of different varieties of commercial soybeans with different planting dates. Experiments were carried out on the Haza del Monte farm in San Jose de la Rinconada in the Province of Seville by the soybean team of the Instituto Nacional (INIA). The farm is representative of irrigated land in the lower half of the Guadalquivir Valley, the principal area of soybean production in Spain.

The 1974 experiment was carried out by Alejandro Agustin Castillo; and the one in 1975, by Francico Montes Agusti. The results have been brought together with those from tests in other regions and published under the title *Tests and Experiment during INIA's 1974-1975 Soybean Seasons (Ensayos y Experiencias de Soja-Campaña 1974-1975 del INIA).*

Apart from this, a detailed study on seed quality resulting from the 1975 experiment has been published by Bartual Pastor and Montes Agusti in the INIA Annals, No. 6, under the title *The Influence on Quality of the Date of Planting (Influencia de la Fecha de Siembra en la Calidad).*

Articles were also published on the same subject in the December 1976 and July 1978 editions of *Agriculture* magazine. These can be consulted for further information.

MATERIALS AND METHODS

The experiments were carried out during the 1974 and 1975 seasons on the estate mentioned at latitude 37° 30' north, 20 meters above sea-level. Figure 1 shows the maximum and minimum temperatures during 1974 and 1975. Figure 2 describes the hours of daylight at La Rinconada Station. The soil is a clay loam.

Flood irrigation was applied before planting, if needed, and as required during the growing season. From 8 to 12 irrigations were used.

The necessary insect control treatments for red spider mites (*Tetranychus urticae* and *Spodoptera littoralis*) were applied.

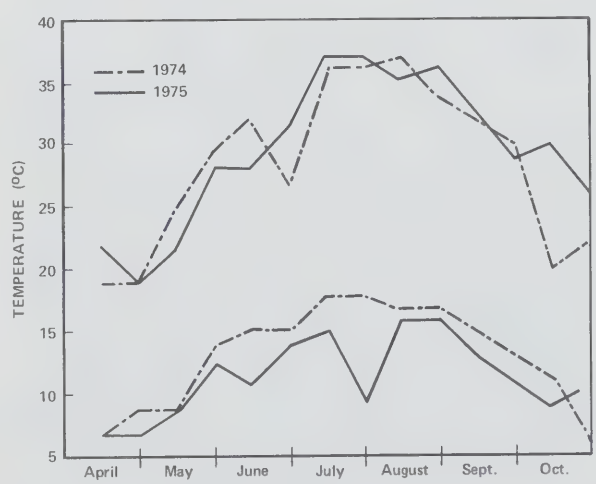

Figure 1. Maximum and minimum temperature means during the 1974 and 1975 growing seasons, La Rinconada, Spain.

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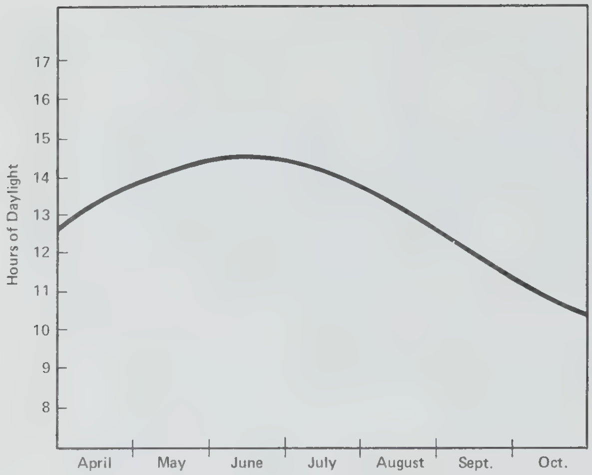

Figure 2. Length of days during the growing season at 37°30' latitude north, La Rinconada, Spain, 1974 and 1975.

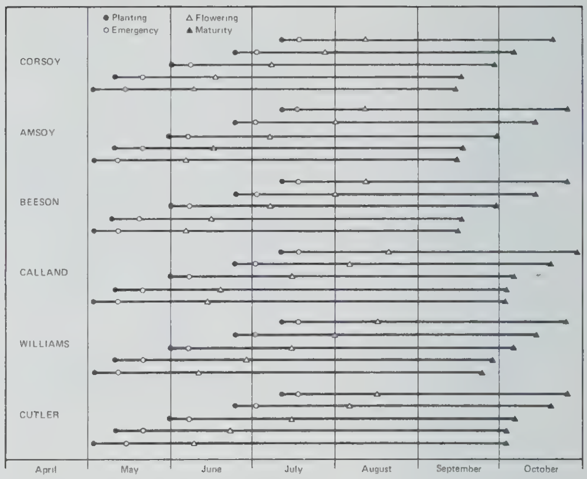

Figure 3. The 1974 growing season: effect of the planting date on the duration of growth phases, 6 soybean varieties, La Rinconada, Spain.

The cultivars Amsoy, Beeson, Corsoy, Williams, Calland, and Cutler were planted. In 1974, trials were planted on May 2, 10, and 31, June 24, and July 11; in 1975, on April 10, May 2 and 23, June 20, and July 10. Phosphorus and potassium were applied at rates of 44 and 104 kg/ha, respectively. Treflan was applied as the herbicide.

The seed was inoculated. In 1975, 25 kg/ha of nitrogen as urea was added near the base of the plant. Nodulation was satisfactory during both years.

Sowing was done by hand, with an average of 30 seeds per meter. The areas sown on each planting date were done in series, not at random. Each area contained 7 treatments in randomized blocks. The treatments were replicated 5 times in 1974 and 4 times in 1975. The blocks contained 4 rows per variety, with rows spaced 0.6 m apart and 10 m long in 1974, and 7 m long in 1975.

Data are included for the number of days from sowing to emergence; days to the beginning of flowering, 50 percent of the plants with 1 flower; days to maturity, 95 percent of the pods turned brown; height of the plants at maturity; height from the ground to the lowest pod; and seed yield (in kilograms per hectare). The moisture content was uniform for all seed harvested from any one planting, but ranged from 8 to 12 percent over all of the treatments.

RESULTS AND DISCUSSION

1. EMERGENCE. The time required for emergence was shortened depending on the lateness of the planting date (Figures 3 and 4). This is attributed to higher temperatures. That fact favors later planting and is very important for a second crop or for double-cropping in the region. The problem is lack of sufficient water in the soil for adequate germination. Preplant irrigation, therefore, is generally necessary.

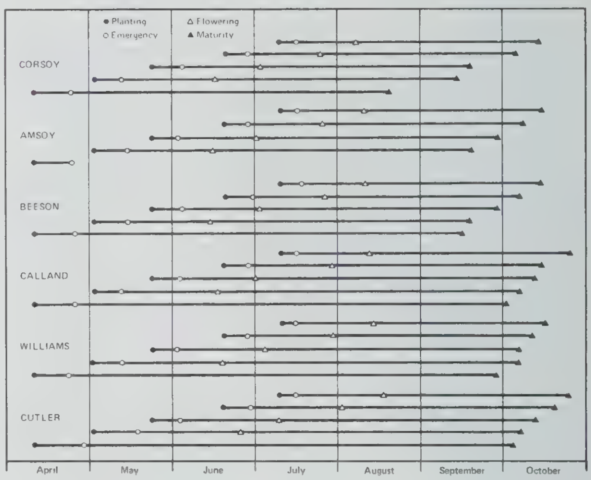

Figure 4. The 1975 growing season: effect of the planting date on the duration of growth phases, 6 soybean varieties, La Rinconada, Spain.

2. BEGINNING OF FLOWERING. The number of days to the start of flowering was influenced by the hours of daylight (Figures 2, 3, and 4). The time from planting to the beginning of flowering was progressively shortened according to how long planting was delayed. The planting date must be one that permits flowering, pod formation, and subsequent plant development to take place

at favorable times with regard to temperatures. The effect of temperature on seed quality, including the oil and protein content, has already been shown.

3. MATURITY. The later the planting date, the more the plant growth cycle was reduced (see Figures 3 and 4). The time to flowering became shorter as the planting was delayed. This was reflected also in less time to maturity.
4. PLANT HEIGHT. Maximum height was attained by the plants seeded in the mid-range of planting dates studied (Tables 1 and 2). With the later plantings, the principal cause of low yields was considered to be the short plants produced.
5. LODGING. The extent of lodging was correlated with the height attained by the plants (Tables 1 and 2).
6. HEIGHT OF THE LOWEST POD. This varied according to the growth characteristics of each variety (Tables 1 and 2). The variability was not as great in later plantings as in the earlier ones.
7. YIELD. The regression constants and correlation coefficients for the effect of duration of development phases on seed yields are shown in Table 3. There was a significant correlation between the number of days to flowering and yield and the time to maturity and yield. The relationships between planting date and yield for each cultivar in 1974 and 1975 are shown in Figures 5 and 6.

Yields were lower for the plantings in early May of 1974 compared to 1975 with Corsoy, Williams, Cutler, and Calland. In 1975, lower yields were observed only with Corsoy and Calland. Early plantings in the Guadalquivir Valley flower when the temperatures are highest, and this may have affected the yield of the crops sown early because of the decrease in flower and pod survival. In both seasons, yields were greatly reduced by planting in late July. Those plantings produced smaller plants and lower positions for the first pod than any others.

The results show that the growth cycle of soybean plants can be predicted for the area of Spain studied. A long growing season does not seem to be necessary for high yields. Soybeans can be planted on a flexible schedule which would permit double-cropping.

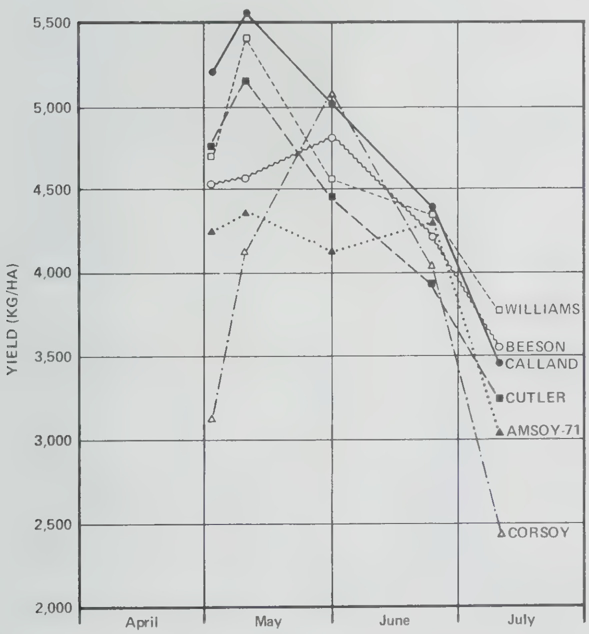

Figure 5. 1974: effect of planting date on yields, 6 soybean cultivars, La Rinconada, Spain.

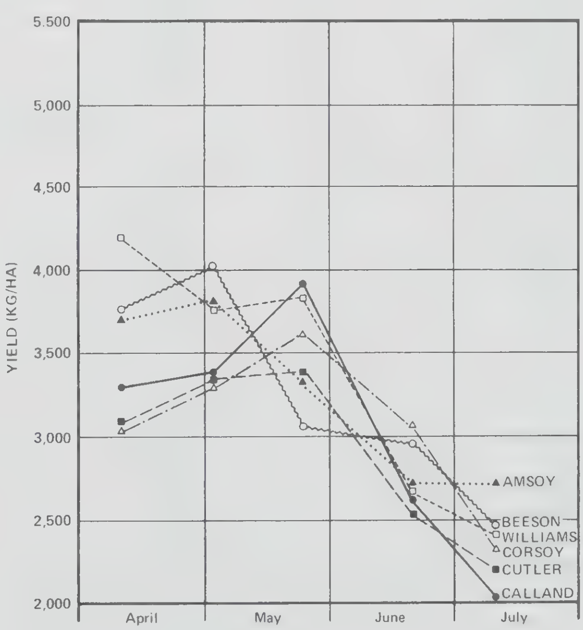

Figure 6. 1975: effect of planting date on yields, 6 soybean cultivars, La Rinconada, Spain.

Table 1. Effect of 5 Planting Dates on Selected Agronomic Characteristics of 6 Soybean Cultivars, La Rinconada, Spain, 1974 Season

Cultivar	Plant height (cm)	Lodging (percent)	Height to lowest pod (cm)
		May 2 planting	
Corsoy	0.72	3.0	4
Amsoy	0.97	3.0	5
Beeson	0.97	2.0	6
Calland	1.19	2.0	9
Williams	1.04	1.0	8
Cutler	1.15	2.0	8
Mean	1.01	2.2	7
		May 10 planting	
Corsoy	0.77	4.0	4
Amsoy	1.00	3.5	6
Beeson	1.00	3.0	6
Calland	1.24	3.0	10
Williams	1.16	2.5	6
Cutler	1.30	3.5	9
Mean	1.08	3.3	7
		May 31 planting	
Corsoy	0.81	5.0	10
Amsoy	1.22	5.0	11
Beeson	1.16	3.0	11
Calland	1.35	4.0	14
Williams	1.19	3.0	14
Cutler	1.39	4.5	14
Mean	1.18	4.1	12
		June 24 planting	
Corsoy	0.80	5.0	5
Amsoy	1.20	3.6	5
Beeson	1.17	3.0	6
Calland	1.25	3.4	14
Williams	1.28	3.0	11
Cutler	1.22	3.5	11
Mean	1.15	3.6	9
		July 11 planting	
Corsoy	0.65	2.5	2
Amsoy	0.91	3.0	2
Beeson	0.87	2.0	2
Calland	0.92	3.0	2
Williams	0.95	2.0	2
Cutler	0.88	3.0	2
Mean	0.86	2.6	2

Table 2. Effect of Planting Date on Selected Agronomic Characteristics of 6 Soybean Cultivars, La Rinconada, Spain, 1974 Growing Season

Cultivar	Plant height (cm)	Lodging (percent)	Height to lowest pod (cm)
	April 10 planting		
Corsoy	0.78	3.0	7
Amsoy	0.96	4.0	10
Beeson	1.03	4.1	11
Calland	1.39	4.0	13
Williams	1.25	2.9	10
Cutler	1.43	3.6	14
Mean	1.14	3.6	11
	May 2 planting		
Corsoy	1.11	3.6	10
Amsoy	1.33	3.8	11
Beeson	1.33	3.7	14
Calland	1.43	4.0	16
Williams	1.25	3.1	10
Cutler	1.48	3.2	20
Mean	1.32	3.6	14
	May 23 planting		
Corsoy	1.25	4.0	15
Amsoy	1.45	3.9	12
Beeson	1.31	3.9	12
Calland	1.44	3.8	14
Williams	1.29	3.4	13
Cutler	1.44	3.9	16
Mean	1.36	3.8	14
	June 20 planting		
Corsoy	1.15	4.0	11
Amsoy	1.26	3.9	13
Beeson	1.21	2.4	14
Calland	1.29	3.8	12
Williams	1.18	3.1	11
Cutler	1.31	3.7	16
Mean	1.23	3.5	13
	July 10 planting		
Corsoy	0.74	1.1	6
Amsoy	0.80	1.1	7
Beeson	0.76	1.1	7
Calland	0.89	1.7	10
Williams	0.79	1.1	8
Cutler	0.88	1.8	12
Mean	0.81	1.3	8

Table 3. Regression and Correlation Data for the Relationship between Growth Phases and Yields of Soybean Seed, at Two Experiments at La Rinconada, Spain, 1974 and 1975

Growth phase (days)	Statistical constants		
	a[a]	b[a]	r[b]
Planting to emergence	3,501	25.0	0.08
Emergence to flowering	1,760	67.2	0.32**
Flowering to maturity	830	35.1	0.53**

[a]Regression equation y = a + bx, where x = days and y = yield in kg/ha.
[b]Coefficient of correlation with yield.
**Significant at the 1 percent level.

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Mechanization Alternatives

J.C. SIEMENS

ABSTRACT: For a given farm size and system of crop and soil management, there is a set of machinery (least-cost set) which will result in the lowest cost. That cost consists of the fixed and variable costs for the machinery itself, the costs for labor required to operate the machinery, and the costs related to the untimely completion of field operations. The size of machines in this least-cost set is determined by how closely the machine productivity (in hectares per hour) matches the combination of farm size and work time available. The available work time is determined mainly by climatic factors and the importance of timely field operations in relation to crop yields.

The principles for selecting the best set of machinery for use on a particular farm are the same regardless of the farm size. For large farms, purchasing most or all of the necessary equipment can be justified. For small farms, equipment rental and hiring machinery to do some custom operations should be considered.

The technology is available to provide almost any degree of mechanization desired for a farm enterprise. But the level of mechanization actually used is constrained by social, economic, and political factors. Thus, gaps often exist that separate the best technical solution for a given mechanization problem from the best practical solution.

THE QUESTION FOR MANY COUNTRIES is whether agriculture should be mechanized and, if so, to what extent. Generally, when soybeans are grown, the soil is tilled extensively before planting and cultivated after planting. Then, the crop is harvested by machine. Using hand labor for any of these operations would be very time-consuming and tedious. So, mechanization for soybean production certainly should be considered seriously and should be adopted if economically feasible.

Mechanization usually reduces labor inputs [Merrill, 1975]. In countries where labor is abundant and inexpensive, the social problems resulting from mechanization are a serious concern and should not be taken lightly [Stout, 1976]. But a man unassisted is not particularly productive in agriculture. True, he can see, judge, discriminate, and anticipate; but he lacks the strength, speed, and endurance of machines.

Mechanization may increase the production of soybeans and other crops because of one or more of the following factors:

1. Better primary tillage and seedbed preparation.
2. Lower harvest losses.
3. Greater precision when planting seeds and applying fertilizers and pesticides.
4. Improved weed control due to mechanical cultivation and the proper use of herbicides.
5. More timely completion of all operations.
6. More intensive land utilization for crops.
7. Less need for animal feed.
8. More land in crop production because of the extra work that can be accomplished with machines.

The reduced drudgery of farm work resulting from mechanization should also be considered. Mechanization would be justified only after a complete accounting of the factors listed previously, plus any benefits resulting from reduced labor costs.

Often, the first step in mechanization is starting to use a tractor for the primary tillage and threshing operations. Tractor power is often made available through custom tractor services of some sort. Mechanization of the primary tillage and threshing operations should be available to farmers before they attempt to produce soybeans, especially where soybeans are to be grown on a commercial basis.

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MECHANIZED SOYBEAN PRODUCTION

Technology and machines are available to mechanize soybean production to almost any extent desired. The commonly available tools for primary tillage include moldboard plows, chisel plows, subsoilers, sweep plows, disk plows, and disks of the heavy-tandem, offset, or one-way type. These tools loosen, fracture, and manipulate the soil to various degrees and leave varying portions of the plant residue on or near the soil surface.

For secondary tillage or seedbed preparation, there are light- and medium-weight disks, field cultivators, an assortment of drags, powered and unpowered harrows, rollers and cultipackers, as well as other machines. Operations can be combined. Many planter variations are available for planting with residue on the surface as well as in a clean, well-prepared seedbed. In addition, seed can be planted on ridges, on a flat seedbed, or in furrows.

Soybeans are harvested with combines in the United States. This is also true in other countries where soybeans are produced on a large scale.

I do not mean to imply that every possible type and size of equipment is available, that it performs perfectly, or that it is suitable for soybeans in every situation. New and improved equipment will continue to be designed and adapted to various situations.

Many of the techniques and machines used for producing grain and row crops can be used for growing soybeans. The primary and secondary tillage requirements for soybeans are similar to those for other crops. Planting and harvesting equipment may deserve special consideration. A uniform planting depth and good contact are important for fast emergence and adequate stands of soybeans. Uneven, rough seedbeds are usually unsatisfactory. Many available planters and drills will satisfactorily meter and plant soybeans in a reasonably well-prepared seedbed [Paulsen and Nave, 1979].

Special combine headers or header attachments specifically designed for harvesting soybeans should be used. According to tests [Nave *et al.*, 1977], combines do a satisfactory job of threshing and cleaning soybeans and cause little damage when the moisture content of the beans is below 13 percent. Generally, soybeans are regarded as an easy crop to thresh. When the machine is properly adjusted, the average threshing loss is less than 0.5 percent of the yield.

The biggest problem when harvesting soybeans by machine is to get the soybeans into the machine without excessive losses. The average loss from a combine equipped with a header commonly used for wheat is 8 to 10 percent of the yield—even in tall, well-standing soybeans; and, of that loss, 85 percent occurs at the header. The losses at the header are the result primarily of shattering (caused by the action of the reel, sickle, and other header parts) and of stubble losses (beans being left on the stubble). Other losses occur because of loose stalks (stalks with beans that were cut but did not get into the combine) and lodged stalks (beans or lodged stalks attached to the ground and not cut). The header losses were reduced to about 6 percent when the standard header was equipped with a floating-type cutter bar and hydraulic header-height controls. Using a new built-in, flexible cutterbar and a new row-crop head, the losses were only 3.8 percent and 1.4 percent, respectively [Nave *et al.*, 1977].

PRINCIPLES OF OPTIMUM MECHANIZATION

If all aspects of soybean production are to be mechanized, the optimum machinery sizes must be determined. Two of the most important factors in such determinations are the cost and availability of labor and the amount of cultivated land on which the machinery is to be used. Other factors include the area of each crop to be produced, the number and types of field operations, the productivity of the available machines, and the penalty cost if the operations are not completed on time. Experimental field data are needed to evaluate many of these factors.

In a qualitative way, Figure 1 [Burrows and Siemens, 1974] represents the relation of machinery size to costs on a specific farm with one laborer performing a given set of field operations. The lowest line in Figure 1 represents the annual changes in fixed and variable machinery costs as the size of machinery increases.

Figure 1 assumes that one man is paid an hourly wage only when he is operating field machines. The labor cost is constant, and

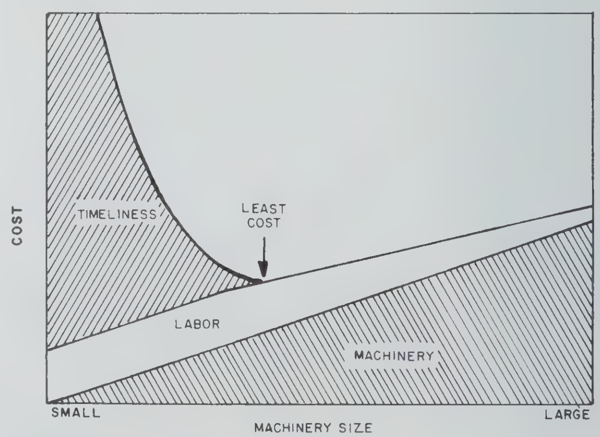

Figure 1. Costs related to machinery size for a specific farm size.

greatest, until the machinery is large enough to reduce total field time below the level of full-time employment. "Full-time" refers to the use of all available time in which field work can be performed. From that point onward, the increasing productivity of larger machines results in a lower and lower labor cost.

The "timeliness" cost is defined as the value of the crop yield that is lost if operations are not completed on time. Before timeliness cost penalties can be determined, field operations must be scheduled. The completion dates of operations such as planting and harvesting may be the key dates that directly affect yields. These dates may be the only ones for which a penalty is assessed. However, planting can be late because the preceding operations were behind time. For example, the plow may be too small, but the planter of adequate size. In that case, the timeliness cost should be ascribed indirectly to plowing, even though the calculations show planting to be the cause. The philosophy, though, should be to assign the timeliness penalty to the system, not just to one operation.

The discussion of timeliness brings into focus the necessity of considering the entire farm enterprise as a system. Soybean production may be only one part of the system; so if considered individually, the analysis would be only a partial one. To be complete, all parts must be combined with a consideration of the interactions betweeen the requirements of the various crops.

The general cost relations shown in Figure 1 indicate that timeliness costs—and, therefore, the total costs—are very high when machinery is too small. The penalty for machinery that is too large is much lower. This relation makes it economical for a farm enterprise to own machinery of a size that allows some of the risks of climate and other factors to be met.

The ordinary delays caused by bad weather, soil conditions unsuitable for field work, or even holidays and breakdowns, reduce the time available in which to complete field operations. The time available can be used more effectively with larger machines or with more machines. Either response requires a greater initial investment.

Because delays vary considerably from season to season, the farmer with the optimum machinery set will have too much machinery capacity for some years, the correct amount for others, and not enough for still others. That is, the least-cost machinery size shown in Figure 1 will be true strictly for only one level of risk induced by a given set of hazards. Most farmers are familiar with the principles of Figure 1 and will decide on the relatively lower added cost (to the right of the least-cost point), rather than chance the high penalty of not finishing critical field operations on time.

For most farming systems, machinery size can be varied the most by changing the size of the tractor(s) or the harvesting equipment. Thus, a three-dimensional graph can be plotted with the axes being the (1) tractor size, (2) size of harvest equipment, and (3) total cost for machinery, labor, and timeliness. The least-cost machinery set will appear as the low point on the surface thus defined.

To determine the least-cost machinery set for a farm, the desired field operations must be listed first. From the list, the necessary equipment to do the operations is selected. The power units should be matched to the implements for tractors and the attachments for combines. The productivity associated with each matched set of machines is calculated by using speed, width, and field efficiency.

The scheduling for all operations is of the utmost importance and is possible only with a knowledge of the time constraints. The number of hours per day available for the field operations is limited both by the availability of labor and by soil conditions. Labor availability usually is known fairly well. However, soil conditions may only be determined in a probabilistic way. The uncertainties involved in predicting weather and in selecting an acceptable probability level make it difficult to generalize over a wide climatic area. As indicated earlier, the level of risk (or the probability of working-time availibility) must be selected by the farmer. Because of long experience, farmers in almost all crop areas have settled on an acceptable risk level. The scientists and engineers, who must examine a whole range of situations, are the ones who have difficulty in quantifying this risk. By computing the cost for several sets of equipment, it is possible to determine the least-cost machinery set for a farm.

It is also possible to examine different tillage systems with the principles described above. For example, Siemens and Burrows [1978] reported the machinery-related costs on a corn-soybean farm in the Corn Belt of the United States. Optimum machinery sets and costs were determined for tillage systems varying from the use of moldboard plowing in the fall with several secondary tillage operations in the spring to the planting of corn and soybeans with no tillage. The optimum machinery set consisted of tractors with power ranging from 112 to 60 kilowatts and combine harvesters of 8 to 4 corn rows for a given farm size. The machinery cost of the no-tillage system was two-thirds that of the moldboard-plow system.

As the tillage system changes, so does the size of the optimum machinery set as well as the types and amounts of other inputs, such

as fertilizers and pesticides. When the costs of these other inputs were included, there was little or no discernable difference in the total costs for the several tillage systems studied.

The effects of farm size on either machinery or labor requirements are less obvious than the effects of tillabe systems. Figure 2 shows how the cost per hectare of machinery, labor, and timeliness were plotted as farm size increased. The costs shown are the least-cost points, as in Figure 1, but with farm size varied. The plot in Figure 2 was derived from actual data, but is shown qualitatively in order to illustrate the principles involved.

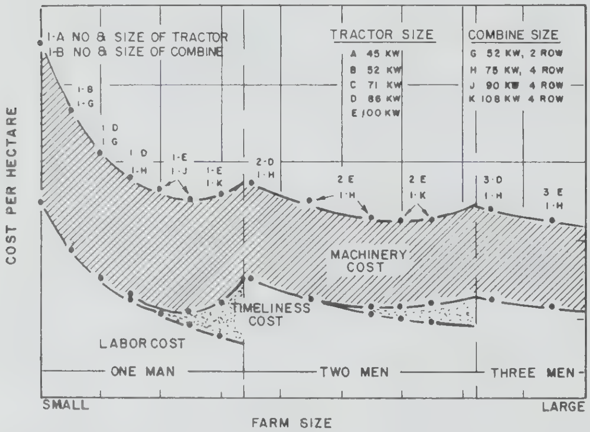

Figure 2. Optimum machinery combinations and related costs for various U.S. maize farm sizes.

At a given labor level, the labor cost per unit of land area decreases with farm size, as expected. Also, as expected, the size of the optimum machinery set increases as the farms become larger. At some point, the largest machinery available would not be able to get the field operations completed in a timely manner. The timeliness penalty then begins to increase.

Finally, the timeliness penalty is equal to the added cost of more machines and labor. Then, another man and machine are added and optimum machine size is reduced. The fixed and variable costs for machinery per unit of land area decrease with farm size.

Only machinery-related costs are shown in Figure 2. The returns from production are not indicated, nor are all the other costs related to production. However, if the crop-management practices are the same, the costs of most other inputs per unit of land area remain constant regardless of farm size. This is in contrast to the cost variability related to tillage systems discussed earlier.

SUMMARY

Technology is available to provide almost any degree of mechanization, or level of any other input, for the farm enterprise. But there are social, economic, and political constraints. Thus, the best technical solutions are often not the ones actually used. Even more important, the failure to account for changes in these constraints is the major cause of unsuccessful technology transfers.

Furthermore, all of the technical factors must be integrated into a single approach before the optimum technology can be determined for a particular farm situation. These factors include, but are not limited to: (1) all of the agronomic factors affecting yields; (2) water management; and (3) mechanization.

Crop and soil scientists and agricultural engineers usually evaluate most of the individual factors according to their respective disciplines, leaving the task of putting the pieces together into a system to the farmer. Little or no consideration is given to the degree to which the individual factors influence the risk level and the practical management of risk.

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Production Costs for Irrigated Soybeans in Egypt and Comparisons with Cotton

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ABSTRACT: What are the economic consequences of growing soybeans on land where cotton could be grown? This question is analyzed first from the view of an individual farmer using existing farm-gate prices and then from that of Egypt as a nation, using international market prices.

Soybeans and cotton are grown in sequence with other crops during one agricultural crop year in Egypt. This paper compares soybean-berseem and cotton-berseem combinations. (Berseem is Egyptian clover.)

Using current farm-gate prices for products and production inputs, the analysis indicates that an individual farmer could increase his farm income by LE 140 per feddan by shifting land from a cotton-berseem to a soybean-berseem combination. However, when world market prices are substituted for farm-gate prices, each feddan of land shifted from cotton-berseem to soybean-berseem loses LE 49 for the nation as a whole. [Conversion factors given at the end of the text.]

WHAT ARE THE ECONOMIC CONSEQUENCES of growing soybeans on land on which cotton could be growing? To an individual farmer, this is a straightforward question of farm management. To a nation, however, there are other implications regarding such things as the balance of trade, food security, and water-resource development.

This paper presents cost-return reports based on farm-gate prices for soybeans, cotton, and berseem (Egyptian clover). The data were provided by Egyptian farmers. Next, partial budgets are used to compare the returns from the cotton-berseem and soybean-berseem combinations. Since soybeans require a shorter growing season than cotton, the returns from berseem are added to the soybean alternative. Then, the budgets are adjusted to show the effect on net income using estimated market prices for crops and market prices for inputs such as chemical fertilizers and insecticides. This, then, permits us to examine the national implications of shifts between these competing crops.

BASIC INFORMATION

Crop-enterprise reports were standardized within the U.S. Department of Agriculture, starting in 1974. Congress required a standardized procedure for computing production costs in order to administer a farm-subsidy program based on the "cost of production." Oklahoma State University produced the system currently in use. Examples of costs for growing soybeans and cotton in several areas of the United States are available [Walker and Kletke, 1971]. Each area of the world has its own system of production, however, and world prices limit the costs that can be incurred under any system unless local governments are willing to subsidize the production. The crop-enterprise reports in this paper follow the standard procedures recognized by the USDA.

Crop-enterprise alternatives can be compared in a logical and concise way by using partial budgets. The process explained in detail by Upton [1973] is followed here. The simplest form of partial budgeting involves the following questions:

1. What extra returns (gains) can be expected?
2. What extra costs will be incurred?

Where the proposed new activities substitute for something already existing, as when one crop substitutes for another or a machine substitutes for labor, we must also ask:

3. What present costs will no longer be incurred?

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Table 1. Partial Budget Used to Estimate the Extra Net Grain from Soybeans at the Farm Level for Egypt

1. SPECIFICATIONS

Plant soybeans to replace cotton. Farm prices are used in the calculations. The government will permit soybeans to be substituted for cotton without any penalty. Soybeans require a growing season of 4 months. Cotton needs 8 months. The 4 months of extra land available because of the shorter growing season for soybeans will be used to produce long-season berseem. The total water requirements for soybeans and long-season berseem are approximately the same as for cotton and short-season berseem. (See the section on water requirements.)

2. ITEMS IN THE PRESENT SYSTEM LIKELY TO BE CHANGED

Cotton stocks will not be available for fuel. More berseem will be available for livestock or for sale. Labor requirements will be lower during the peak harvesting season for cotton and rice, which is reflected in lower labor costs.

3. ESTIMATED GAINS AND LOSSES

Gains	Losses
a. Extra returns: Income from soybeans. Income from long-season berseem.	c. Extra costs: Producing soybeans. Producing long-season berseem.
b. Reduced costs: Production costs for cotton.	d. Reduced returns: Income from cotton. Cotton stocks.

THE NET GAIN EQUALS (a plus b) minus (c plus d).

4. What present income will be sacrificed?

Hence, the gain will be the sum of items 1 and 3, the extra returns plus the saved costs. The total cost will be the sum of items 2 and 4, the extra costs plus the present income foregone. The total gain minus the total cost, then, represents the net gain or expected increase in profit.

The first step in partial budgeting should be to specify the proposed change, stating clearly what is involved and when it occurs. Second, would be to list the items in the existing system that are likely to be changed when the new policy is introduced. Doing this reduces the likelihood of omitting possible indirect effects of the change.

Upton proposes the following format, Table 1, which is used in this report.

Estimating costs and returns is fraught with difficulties. The analyst simply has to make the best of the resources at hand and must be willing to regard the results as tentative. If better information becomes available, the analyst must be willing and anxious to revise the partial budget.

Two problems with partial budgeting should be mentioned. First, the performance among farmers usually is different, and the variability that exists around the figures used in a partial budget should be recognized. Second, the figures used in a partial budget are based on expected events. Actual occurrences, especially those involving prices and yields, can vary considerably from expectations.

CROP ENTERPRISE REPORTS

Before continuing with the partial budget analysis of shifting from cotton to soybean production, let us review the data to be used in the partial budgets. Tables 2 through 5 depict typical enterprise costs and returns for soybeans, cotton, and berseem in the Kafr El Sheikh Governorate of Egypt in 1978. The data are based on interviews with farmers and on observations made by staff members assigned to the Egyptian Water Use Project. The cost-return reports on crop enterprises are followed by partial budgets, which are used to analyze the shift from cotton to soybeans.

The cost-return reports use current Egyptian farm-gate prices to determine income in the cost-return tables. These prices will be modified later in the analysis.

Concerning the costs and returns in Table 5, higher fall and spring prices result in a higher average value for long-season berseem than for the short-season crop. Berseem is not usually planted in August because it does not grow well in the hot temperatures typical of that month. Long-season berseem is also subject to damage by cotton leaf

Table 2. Soybeans: Cost and Returns, 1 Feddan, Kafr El Sheikh Governorate, Egypt, 1978

	Unit of measurement	Number of units	Price or value per unit (LE)[a]	Income or cost (LE)[a]
INCOME				
Soybeans	kilograms	900	0.200	180
VARIABLE COSTS				
Apply organic fertilizer	square meter	20	0.600	12
Plow with tractor (3x)	feddan[b]	3	2.000	6
Smooth with cows and drag	hour	2	0.500	1
Furrow with tractor	feddan[b]	1	2.000	2
Clean ditch	man-hour	10	0.200	2
Seed	kilograms	40	0.300	12
Plant seed by hand	woman-day	4	0.500	2
Irrigate	hour	4	0.470	2
Reshape furrows using a donkey and a small plow	hour	2	0.270	1
Hoe	man-hour	20	0.200	4
Fertilizer (55 days after planting, 33-0-0)	kilograms	50	0.050	3
Labor to spread fertilizer	boy-hour	15	0.060	1
Irrigate	hour	4	0.470	2
Hoe	man-hour	20	0.200	4
Fertilizer (33-0-0)	kilograms	50	0.050	3
Irrigate	hour	4	0.470	2
Weed	man-hour	10	0.200	2
Irrigate	hour	3	0.470	1
Weed	man-hour	10	0.200	2
Irrigate	hour	3	0.470	1
Insecticide	kilograms	3	1.000	3
Rent of sprayer (3x)	feddan[b]	3	0.650	2
Labor for spraying	man-hour	15	0.200	3
Irrigate (2x)	hour	8	0.470	4
Cut by hand	man-hour	30	0.200	6
Transport by camel	load	6	0.300	2
Labor to load camel	woman-day	4	0.600	2
Thresh with tractor	hour	2	2.000	4
TOTAL, VARIABLE COSTS				91
GROSS MARGIN PER FEDDAN				89
GROSS MARGIN PER MONTH				22

Assumptions: (1) The previous crop was berseem. (2) Soybeans are planted on April 1 and harvested on July 30. (3) The government shares equally the cost of insecticide. Thus, the full cost would be LE 6. (4) Irrigation water is free except for the cost of lifting and distribution. These costs, on an hourly basis are:

Rent of 2 cows	LE 0.17
Labor to distribute water	0.17
Boy to chase cows . .	0.05
Rent of sakia	0.08
	LE 0.47 per hour

[a]One Egyptian pound equalled $2.556 in 1978 (average value, Federal Reserve Bank, Chicago).

[b]One feddan equals 0.420 hectare (1.038 acres).

Table 3. Cotton: Cost and Returns, 1 Feddan, Kafr El Sheikh Governorate, Egypt, 1978

	Unit of measurement	Number of units	Price or value per unit (LE)[a]	Income or cost (LE)[a]
INCOME				
Seed cotton	kantar[b]	5	35.000	175
Stalks	camel load[c]	5	3.000	15
TOTAL, FARM INCOME				190
VARIABLE COSTS				
Apply organic fertilizer	square meter	20	0.600	12
Plow with tractor (3x)	feddan[d]	3	2.000	6
Smooth with cows and drag	feddan[d]	1	2.000	2
Furrow with cows and plow	feddan[d]	1	2.000	2
Clean ditch	man-hour	10	0.200	2
Smooth with cows and drag	feddan[d]	1	1.000	1
Seed	kaila[e]	7	0.300	2
Plant seed by hand	woman-day	4	0.500	2
Chemical fertilizer:				
Super phosphate (0-5.5-0)	kilograms	100	0.022	2
Amonium Nitrate (33-0-0)	kilograms	200	0.050	10
Spread fertilizer by hand	hour	10	0.200	2
Irrigate	hour	6	0.470	3
Thin by hand	boy-day	3	0.300	1
Hoe (2x)	man-hour	28	0.200	6
Irrigate	hour	4	0.470	2
Hoe	man-hour	14	0.200	3
Irrigate (7x)	hour	28	0.470	13
Weed (3x)	boy-day	6	0.500	3
Pick insect eggs as needed	feddan[d]	1	9.000	9
Chemical control of insects	feddan[d]	1	8.000	8
Pick by hand (3.5 kantar)	woman-day	20	0.500	10
Pick by hand (1.5 kantar)	woman-day	20	0.500	10
Transport seed cotton	feddan[d]	1	1.000	1
Cut stalks	man-hour	25	0.200	5
Transport stalks	camel-load[c]	5	0.500	3
Labor to load stalks	man-hour	5	0.200	1
TOTAL, VARIABLE COSTS				121
GROSS MARGIN PER FEDDAN				69
GROSS MARGIN PER MONTH				9

Assumptions: (1) The previous crop was berseem. (2) Cotton is planted March 1 and the stalks are removed from the field on October 31. (3) The government shares equally the cost of insect control. The full cost would be LE 34 per year. (4) Irrigation costs on an hourly basis are the same as for soybeans (see Table 2).

[a]One Egyptian pound (LE) was equal to $2.556 in 1978 (average value, Federal Reserve Bank, Chicago).

[b]One kantar of seed cotton equals 157.5 kilograms.

[c]One camel load equals 250 kilograms.

[d]One feddan equals 0.420 hectare (1.038 acres).

[e]One kaila equals 16.5 liters.

Table 4. Short-Season Berseem: Costs and Returns, 1 Feddan, Kafr El Sheikh Governorate, Egypt, 1978

	Unit of measurement	No. of units	Price or value per unit (LE)[a]	Income or cost (LE)[a]
INCOME				
Two cuts in 4 months	tonne	13	5.000	65
VARIABLE COSTS				
Seed	kaila[b]	1.5	8.000	12
Chemical fertilizer				
Super phosphate (0-15-0)	kilograms	50	0.022	1
Ammonium Nitrate (33-0-0)	kilograms	50	0.050	3
Spread seed and fertilizer	man-hour	4	0.200	1
Irrigate (3x)	hour	12	0.470	6
TOTAL, VARIABLE COSTS				23
GROSS MARGIN PER FEDDAN				42
GROSS MARGIN PER MONTH				11

Assumptions: (1) The previous crop was cotton. (2) Short-season berseem is planted in November and the second cut is made in February. (3) Irrigation is on an hourly basis, at a cost of LE 0.47 per hour. (4) Berseem is usually sold by the "kerat cut" as it stands in the field. One feddan has 24 kerat cuts, weighing 6.5 tonnes as green forage. (5) The market value of berseem in mid-winter is lower than in the fall and spring because supplies are abundant in the winter.

[a]One Egyptian pound (LE) equalled $2.556 in 1978 (average value, Federal Reserve Bank, Chicago).

[b]One kalia equals 16.5 liters.

Table 5. Long-Season Berseem: Costs and Return, 1 Feddan, Kafr El Sheikh Governorate, Egypt, 1978

	Unit of measurement	Number of units	Price or value per unit (LE)[a]	Income or cost (LE)[a]
INCOME				
Five cuts in 8 months	tonne	33	6.000	198
VARIABLE COSTS				
Seed	kaila[b]	1.5	8.000	12
Chemical fertilizer				
Super phosphate (0-15-0)	kilograms	100	0.022	2
Ammonium Nitrate (33-0-0)	kilograms	50	0.050	3
Spread seed and fertilizer	man-hour	4	0.200	1
Irrigate (10x)	hour	40	0.470	18
TOTAL, VARIABLE COSTS				36
GROSS MARGIN PER FEDDAN				162
GROSS MARGIN PER MONTH				20

Assumptions: (1) The previous crop was soybeans. (2) Long-season berseem is planted in September and the last cut is made in March. (3) Irrigation is on an hourly basis, at a cost of LE 0.47 per hour. (4) Berseem is usually sold by the "kerat cut" as it stands in the field. One feddan has 24 kerat cuts, weighing 6.5 tonnes each as green forage.

[a]One Egyptian pound (LE) equalled $2.556 in 1978 (average value, Federal Reserve Bank, Chicago).

[b]One kalia equals 16.5 liters.

worms during that period. One might consider following soybeans with a crop of corn forage before planting berseem, which might or might not be profitable.

The variable costs purport to include all such costs. We intend to include all costs actually paid by a farmer, plus the market value of human labor and other inputs supplied by the farmer and his family. The gross margin can be explained as the "residual return to land, water, the farmer's management, and unpaid services such as may be supplied by government." Thus, any land rents, taxes, and returns to management must be paid out of the gross margin.

Keep in mind that the return to a farmer may exceed the gross margin if he pays no rent or taxes and if labor and animal power are supplied by him, his family, and his own animals. Each farmer's actual income from any crop will depend on his tenure status (whether he owns or rents the land), the amount of labor he and his family supply, and the amount of power and organic fertilizer supplied by his animals.

ANALYSIS OF SHIFTS FROM COTTON TO SOYBEANS: A FARMER'S POINT OF VIEW

Let us consider the question: Would it benefit a farmer to shift from cotton to soybeans? For an analysis, it is appropriate to use farm-gate prices as in the crop-enterprise reports.

Cotton occupies the land from March 1 through October; soybeans, from April 1 through July. When the land is not in these crops, it can be producing any one of a number of suitable fall and winter crops. This analysis assumes that the off-season crop is berseem.

Part 3 of the partial budget outline from Table 1 is now reproduced. The values for cost and income changes have been inserted, taken from Tables 2 through 5. The partial budget is shown in Table 6.

Given the current prices paid to farmers, soybeans look profitable. It should be noted that of the total cost (LE 294), 65 percent is associated with reduced returns from cotton. Of the total gain (LE 434), 28 percent occurs because cotton would not be produced and 31 percent because of selling berseem. If cotton is an alternate crop to soybeans, the cost and returns associated with cotton have a great effect on the cost of producing soybeans. Similarly, if berseem production is increased as a result of shifting to the long-season variety, then the livestock price policy, which controls the price of berseem, is of considerable importance. Clearly, the issue requires more than an examination of existing prices for soybeans and cotton.

If all of the prices and costs used were generated by a market system and if no external factors existed, we could simplify matters and say that, what is good for the farmer is good for the nation. The reverse would also hold: What is good for the nation is also good for the farmer. However, if government policies generate different prices for the outputs and inputs than ones that would have occurred under a competitive market system, the congruence might not occur.

Many countries in the world, including Egypt, have such policies. Therefore, it is appropriate to ask a second question, which can also be dealt with by using a partial budget: What is the cost at the national level of producing soybeans? The question is broader now, but at least a start can be made by using a partial-budget approach.

Table 6. Partial Budget in which Soybeans and Long-Season Berseem Replace Cotton and Short-Season Berseem (from Table 1, Part 3)

ESTIMATED GAINS AND LOSSES	
EXTRA RETURNS:	EXTRA COSTS:
Income from soybeans, LE 180[a]	Irrigation and fertilizer for long-season berseem, LE 13[c,a]
Income from 3 cuts berseem, LE 133[b,a]	Producing soybeans, LE 91[a]
REDUCED COSTS:	REDUCED RETURNS:
Producing cotton, LE 121[a]	Income from cotton, LE 190[a]
TOTAL GAINS, LE 434	TOTAL COSTS, LE 294
NET GAIN = 434 - 294 = LE 140 PER FEDDAN	

[a]One Egyptian pound (LE) equalled $2.556 in 1978 (average value, Federal Reserve Bank, Chicago).
[b]The difference between gross income from long-season berseem and short-season berseem, reflecting a combination of yield and price differences.
[c]The only additional costs of producing long-season berseem over short-season berseem are for fertilizer and 7 extra irrigations.

ANALYSIS OF SHIFTS FROM COTTON TO SOYBEANS: A NATIONAL VIEWPOINT

The accounting cost of any input should be based on the concept of opportunity cost. If a farmer purchases fertilizer for application to a cotton crop, the fertilizer cost should be based on what the farmer must give up in order to make the purchase. The price the farmer pays, even a subsidized one, is usually a good indicator of the opportunity cost.

The price a farmer receives for a product—say cotton—also provides a good estimate of the opportunity cost the farmer would incur if he did not sell the product. For example, it would "cost" a farmer about LE 35 if he *did not sell* a kantar of seed cotton (or LE 222 per tonne). However, these values for "buying" and "selling" may not be the appropriate ones to use at the national level. If the farmer's price for fertilizer is a subsidized one, then the farmer's cost for fertilizer will understate the opportunity cost of fertilizer for the nation. If the farmer receives a price for his cotton which is half of the equivalent export price, then the price the farmer receives will understate the opportunity cost for the nation of not having a tonne of cotton for sale.

Let us say that the farm price for cotton is half the export price for cotton, and that the farm price for soybeans is greater than the import price. It would be inappropriate to use these prices in constructing a national-level partial budget for soybeans compared to cotton. Although appropriate for the individual farmer, such prices would overvalue soybeans and undervalue cotton at the national level.

If soybeans are produced instead of cotton, a nation foregoes the opportunity of selling cotton and of buying soybean products. Of course, other issues such as food security are involved; but even there, policymakers should have information about the opportunity cost of additional amounts of something of real but intangible value, such as food security.

The results of a national-level analysis are different than when considering the individual farmer's point of view. This is illustrated in Table 7. The shift of a feddan from cotton and short-season berseem to soybeans and long-season berseem would be desirable for a farmer, increasing his income by LE 140. But apparently, such a shift would be undesirable for the nation, reducing its income by LE 49 per year for each feddan so shifted. After accounting for the policy variable affecting the indirect tax imposed on cotton and the subsidies given to inputs, the advantage for Egypt of shifting to soybeans becomes questionable.

Table 7. Partial Budget Used to Estimate the Extra Net Gain from 1 Feddan of Soybeans at the National Level, Egypt, 1978

1. SPECIFICATIONS

Planting soybeans (an import crop) to replace cotton (an export crop). Soybean and cotton prices approximate net import prices and export prices, respectively. Costs reflect market prices for fertilizer, insecticides, seeds, and machinery.

2. ITEMS IN THE PRESENT SYSTEM LIKELY TO BE CHANGED

Costs will be incurred to produce soybeans and long-season berseem. Income will increase from these crops. Costs of producing cotton will be saved, but the income from that crop will be lost.

3. ESTIMATED GAINS AND LOSSES

Gains	Losses
a. Extra returns: Income from soybeans, LE 180[a] Income from 3 cuts of berseem, LE 133	c. Extra costs: Irrigation and fertilizer for long-season berseem, LE 13 Producing soybeans, LE 103 (LE 91 x 1.14)[b,a]
b. Reduced costs: Producing cotton, LE 176[a] (LE 121 x 1.46)[b,a]	d. Reduced returns: Income from cotton, LE 422[a] (LE 190 x 2.22)[b,a]
TOTAL GAINS, LE 489[a]	TOTAL COSTS, LE 538[a]

THE NET LOSS EQUALS 538, MINUS 489, OR LE 49 PER FEDDAN.

[a]One Egyptian pound (LE) equalled $2.556 in 1978 (average value, Federal Reserve Bank, Chicago).

[b]Production cost and income values are adjusted by these coefficients, which were estimated with the assistance of various people in the Ministry of Agriculture and the Ministry of Economics and Foreign Trade.

A high price for berseem helps make the soybean alternative attractive, since long-season berseem captures the advantages of greater yields and higher seasonal prices. However, a government policy allowing unrestricted imports of meat would cause a decline in domestic meat prices and, subsequently, in berseem prices. The demand for berseem is derived at least partly from the demand for meat. Lower meat prices would reduce the demand for berseem; hence, the market price of berseem would decline.

WATER REQUIREMENTS

Any analysis of cropping strategies for Egypt must consider water requirements. Since information about water-use requirements for irrigated soybeans is not available, the authors assumed those requirements to be the same as for summer corn. The water requirements for corn, cotton, and berseem, taken from two sources, are summarized in Table 8.

Table 8 indicates that the data from the two sources are in conflict, i.e., source one indicates the highest requirements for the berseem-soybean combination while source two indicates the highest requirements for berseem-cotton. Perhaps there is not enough difference in the requirements to merit much concern at this stage of Egypt's land-water resource balance. By the time new lands are developed, however, the land-water balance will become more critical. So, additional crop-water requirement data should be made available to help the policymakers. If soybeans are to become a more important crop in Egypt's future, studies should be started immediately to determine the crop's water requirements.

CONVERSION FACTORS

1 feddan equals 0.420 hectare (1.038 acres).
1 feddan equals 24 kerat cuts (6.5 tonnes each).
1 kantar of seed cotton equals 157.5 kilograms.
1 kaila equals 16.5 liters.
1 camel load equals 250 kilograms.
1 metric tonne equals 2,205 pounds.
1 Egyptian pound (LE) was equal to $2.556 in 1978 (average value, courtesy of the Federal Reserve Bank in Chicago). On February 29, 1981, the exchange rate was 1 LE = $1.45 (courtesy of Continental Illinois National Bank, Chicago).

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Table 8. Water Requirements per Feddan, Alternate Cropping Systems, Egypt, 1978

Cropping system	Irrigation water: Source (El Tobgy, 1976)	(Source, Kramer) CWR[a]	CWR + EL[b]
		cubic milliliters	
Berseem, full season	2,220	1,961	3,080
Soybeans (maize)	2,500	3,337	4,909
	4,720	5,298	7,989
Berseem, catch	1,375	1,230	1,747
Cotton	3,250	4,650	6,954
	4,625	5,880	8,701

[a]Crop water requirements.
[b]Crop water requirements plus conveyance and efficiency losses.

Country Reports

Irrigated Soybean Production in Bangladesh

A. KHAIR

BANGLADESH SUFFERS FROM BOTH FLOOD AND DROUGHT. Although there is abundant rainfall during the June to September monsoon season, drought conditions exist during the October to May dry period. Soybeans and other crops that are generally grown during the dry period need irrigation. But, at the present time, only about 12 percent of the total cultivable land has the irrigation facilities to meet full or partial water demands. About 90 percent of the population depends on agriculture and agricultural industries for their living. But the daily diet of the common people in Bangladesh is deficient in protein, fat, and vitamins.

Soybeans are one of the richest sources of high-quality plant protein and fat, with a protein content of about 40 percent and an oil content of about 20 percent. The total food supply of an average Bangladeshi is about 861 grams per day and only 3 grams is oil or fat. Even with this low level of fat and oil consumption, the government imports a large quantity of soybean oil every year. Because soybeans are so important as a food crop and as an oil crop, the government has launched a comprehensive program to promote the large-scale production of soybeans. The Bangladesh Coordinated Soybean Research Project was established in 1975 to conduct research on the introduction, cultivation, and use of soybeans in Bangladesh.

Agricultural conditions in Bangladesh are ideal for producing soybeans throughout the year. Soybean yields compare well with the yields of other oil-producing crops. Not only soybean oil, but soybean cake, bread, and milk are very popular.

PRODUCTION TECHNOLOGY

Area Under Irrigated Soybean Production

Only a few hundred hectares of land are now under irrigated soybean cultivation. The Bangladesh Coordinated Soybean Research Project and the Mennonite Central Committee are trying to popularize soybeans in Bangladesh. It is expected that a large portion of cultivable land will be planted to soybeans by the Bangladesh Agricultural Development Corporation, the Directorate of Agriculture (Extension and Management), the Mennonite Central Committee, and the Bangladesh Coordinated Soybean Research Project. From the record of the last few years, the observation can be made that the average yield of soybeans in Bangladesh is very encouraging, ranging from two to three tons per hectare, depending on the management practices used and the season of production.

Cultural Practices

Generally, a country plough drawn by a bullock is the method used to cultivate the land. After three or four ploughings and levelling by a country ladder, the land is ready for sowing. Both line sowing and broadcast sowing are used. Row spacing of 30 centimeters and plant spacings of 5 centimeters are maintained in line sowing. Production of soybeans without tillage operations, mainly after transplanted rice is harvested, is also very promising. There are three seasons for growing soybeans, a December and January planting for commercial production, a September and October planting for seed and production purposes, and a July and August planting for producing seed. Eighty-five to 100 kilograms of seed per hectare are required for line sowing and 100 to 155 kilograms of seed are required for broadcast sowing. The crop matures in 90 to 120 days, depending on the growing season and the varieties that were planted. Irrigation is required for December and January planting but is not needed during other growing seasons. Water is generally applied in the soybean field by flooding

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(wetting the land surface). Other irrigation methods have not yet been introducted.

Cropping Patterns

Crop rotation is practiced in Bangladesh. The sequences that are followed to produce soybeans throughout the year are shown below.

i) March-April rice--soybeans--vegetables

ii) March-April rice--June-August rice--soybeans

iii) jute--soybeans--soybeans

The suitability of intercropping soybeans needs further study, but the results of a few intercropping trials of soybeans with sugarcane, wheat, or rice are encouraging. In January, irrigation is necessary, but, during other seasons, irrigation is generally not needed.

Varieties

Three varieties of U.S. origin have been selected by the Bangladesh Coordinated Soybean Research Project after a large number of trials. These varieties are Davis, Bragg, and Lee-74.

Fertilizers

The following fertilizers are used for soybean cultivation: 20 kilograms of nitrogen per hectare as urea, 60 kilograms of P_2O_5 per hectare as triple superphosphate, and 40 kilograms of K_2O per hectare as muriate of potash. One-half of the urea and all of the triple superphosphate and muriate of potash are applied when the land is prepared for planting, and the balance of the urea is applied four weeks after planting.

Rhizobium

Twenty-four strains of *Rhizobium japonicum* have been isolated and tested at three different stations. The test results are encouraging for three strains, but they are still in the experimental stage. The present rate of inoculation of NITRAGIN is 10 grams per kilogram of seeds.

Mechanization

Except for a few cases, all cultural practices are done with traditional implements. Farm mechanization has not yet become popular because of cropping patterns, economic conditions, and cost.

Irrigation

The sources of irrigation water are canals, tanks, and tube-wells. Irrigation practices are carried out either by traditional methods or by introducing low-lift pumps and tube-well irrigation projects. Irrigation water is applied in the field by flooding. Generally, two irrigations are needed for the January soybean planting, each with a depth of 6 to 8 centimeters, one 25 to 30 days after planting and another immediately after flower-bud differentiation. Occasionally one more irrigation is needed during the pod-setting period if drought conditions occur. For the early January planting, the soybean crop uses about 25.4 cemtimeters of water in Bangladesh. During the other seasons, irrigation is generally not needed; moreover, proper drainage is needed for July to August planting.

Plant Protection

Soybeans in this region are found to be infested by the following insects and diseases:

Insects	Diseases
a) Leaf roller	a) Anthracnose
b) Hairy caterpillar	b) Bacterial pustule
c) Aphid	c) Foot and root rot
d) Meal moth	d) Yellow mosaic

The damage caused by insect infestation and disease is not serious. Two or three applications of insecticides and fungicides are are required to control the insects.

Seed Production

The climate of Bangladesh favors the year-round production of soybeans. July and August and September and October plantings are generally used to grow the crops for seed. The Bangladesh Coordinated Soybean Research Project and the Mennonite Central Committee

have undertaken some programs to produce seeds to distribute among the farmers. The viability of seeds is a major problem. Traditional and modern seed storage methods have been tested. The traditional, local earthenware pot with a layer of soil was effective, although using double-layered polythelene bags or cold storage was more effective.

Yields

The average farmers' yield ranges from 1,500 kilograms per hectare to 2,000 kilograms per hectare. At experiment stations under high-level management practices, the average yields range from 2,500 kilograms per hectare to 3,500 kilograms per hectare.

Cost of Production

At present, the cost of producing irrigated soybeans is about U.S. $187 per hectare. For irrigated wheat the cost of production is U.S. $244 per hectare. The net return from producing soybeans is about U.S. $42 per hectare and the return from wheat is only U.S. $12.00.

Constraints

Soybeans are not yet widely grown in Bangladesh. Only about 12 percent of the total cultivable land is under irrigated agriculture, mainly to produce rice and wheat. Seed viability, the lack of irrigation facilities, and crop competition from wheat, mustard, and rice, are the major constraints in irrigated soybean production.

Research Publications

The Bangladesh Coordinated Soybean Research Project has been conducting research on various aspects of soybean introduction, cultivation, and use since 1975. The research is presented in the following reports:

Annual Report, Bangladesh Coordinated Soybean Research Project, BARC, No. 1, 1975-1976.

Annual Report, Bangladesh Coordinated Soybean Research Project, BARC, No. 2, 1976-1977.

Annual Report, Bangladesh Coordinated Soybean Research Project, BARC, No. 3, 1977-1978.

Annual Report, Bangladesh Coordinated Soybean Research Project, BARC, No. 4, 1978-1979.

Soybean Research Abstract, Vol. 1, 1978.

ORGANIZATION

The organizations associated with the soybean development program are the Bangladesh Coordinated Soybean Research Project, the Bangladesh Agricultural Development Corporation, the Directorate of Agriculture (Extension and Management), and the Mennonite Central Committee.

All of these organizations, except the Mennonite Central Committee, work under the Ministry of Agriculture. The Mennonite Central Committee is a foreign organization and works separately in introducing soybeans into Bangladesh as a food grain.

Research Facilities

The Bangladesh Coordinated Soybean Research Project was established to work in collaboration with the leading research institutes of the country. Most of these institutes have trained manpower and well-equipped laboratories to conduct research on various aspects of soybean production.

The Bangladesh Coordinated Soybean Research Project is currently conducting research on irrigation practices and water management with the following personnel and facilities:

Personnel	Level of training	Laboratory facilities
1. Principal Investigator	B. Sc. Agri. Engg., M. Engg.	The laboratory facilities of the Bangladesh Agricultural University are being used. The university has one field station and one irrigation laboratory that are not well equipped.
2. Scientific Officer	B. Sc. Agri. Engg.	

The following personnel and facilities will be needed for the irrigated soybean program in the next ten years:

1. Two Principal Investigators (Ph.D. in Irrigation Engg.)
2. Five Investigators (M. Engg. in Irrigation Engineering)
3. Ten Field Assistants (B. Sc.)

In addition to the above personnel, the project will need five well-equipped field stations and one irrigation laboratory.

Irrigated Soybean Production in Colombia

G. BASTIDAS RAMOS

IN COLOMBIA, SOYBEANS ARE THE CROP that has received the most attention in recent years. Soybeans represent 14 percent of Colombia's edible oil production and 44 percent of its production of protein concentrates. Soybeans have also received attention because of their importance as a good source of protein for human consumption, and they have been included in government nutrition programs. Ninety-eight percent of the crop is located in the Cauca River Valley, but there are also some areas where soybean production could be intensified, especially in the cotton-growing areas on the Atlantic coast and around the cities of Tolima and Huila. If soybeans are considered as an alternative to or a rotation crop with cotton, there are approximately 100,000 hectares on the Atlantic coast and around 25,000 hectares in the Tolima-Huila area that are potential soybean-producing areas. These 125,000 hectares could easily yield 187,500 metric tons of soybeans, which would meet the domestic demand for soybean meal and partially cover the shortage of edible oil. Soybeans produced in Colombia are processed for oil and for soybean meal that is used in concentrates for livestock. Only 2 percent of Colombia's soybean production is processed for human consumption.

PRODUCTION

Soybeans are a relatively new crop in Colombia. In 1960, there were 10,000 hectares of soybeans, yielding 1.5 metric tons per hectare. In recent years, the growing area has increased to 70,000 hectares with yields from 1.8 to 2.1 metric tons per hectare. These yields give Colombia the highest yield per unit area of the countries with high yields of soybeans.

TECHNOLOGY

The soybean crop is one of the most specialized crops in Colombia. The seed varieties used have maturity periods of 100 to 110 days, and, because of the climatic conditions of the area (average temperature of 24° C., 900 to 1,000 meters above sea level, 1,000 millimeters of rainfall per year), two crops are produced each year. The first crop is planted during March and early April and is harvested in June and July. The second crop is planted in September and early October and is harvested at the end of December and in early January. The second crop represents 65 percent of the total annual production.

Disc and chisel plows are used to prepare the soil. Generally, one plowing (20 centimeters deep) and two passes with a spring-tooth harrow are needed. The planting of soybeans is mechanized, both when soybeans are grown as a single crop and when they are grown in rotation with cotton, corn, and sorghum. In recent years, some double-cropping with sugar cane has been developed. Studies have been conducted on the seeding rate and its effect on growth and yield have been determined. Based on experimental results, some specific recommendations have been made to soybean growers in the Cauca Valley. For the varieties Mandarin S4-ICA, Pelican SM-ICA, ICA Caribe, ICA Lili, Victoria, and SV-77, 60 centimeter rows and 70 kilograms of seed per hectare are recommended, and for the varieties Davis and ICA Tunia, 40 to 50 centimeter rows and 80 to 100 kilograms of seed per hectare are recommended. In recent years, ICA Tunia and ICA Lili have been used on 90 percent of the fields. These two varieties have been developed through crossbreeding and selection. The others are selected from varieties that have been imported from the United States.

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Studies on natural rainfall needs have determined the required levels of moisture for soybeans for maximum yields. These levels have been taken into consideration in planning for irrigation. These studies have shown that good yields are obtained with 470 millimeters of water, distributed during the growing and maturing periods. The area where soybeans are presently grown needs two to three supplemental irrigations of 20 to 30 millimeters each. Thirty-five percent of this area is presently irrigated. Water sources for irrigation are deep wells and surface water. Sprinkler systems are used to irrigate the fields.

Several fertilization trials have been done with major elements (nitrogen, phosphorus, and potassium) and also with minor elements (zinc, boron, copper, molybdenum, iron, and manganese). The results have shown no effect on yield if the soil is well managed (rotation, drainage, and so forth). In some areas, the application of 25 kilograms of nitrogen per hectare increases yields 300 kilograms per hectare. The application of phosphorus in the southern area of the Cauca Valley has increased yields because of the acidity of the soil. Application of minor elements has also shown some response in several areas from using zinc. Under the conditions in the Cauca Valley, inoculants have not increased yields, which shows the good adaptation of the native varieties as compared with imported varieties. Weeds are controlled with herbicides that are applied preemergence, but postemergence herbicides were used. Cultivation and manual weeding are done once, approximately 20 to 35 days after emergence.

All crop operations except harvesting are mechanized. Harvesting, which is done both manually and with machinery, represents 95 percent of the total labor needed to produce a crop. The manual-mechanized method is accomplished by pulling the plants by hand and grouping 8 to 10 rows in windrows or *chorras* that, in turn, are picked up by a combine that threshes and sacks the soybeans in one operation. Studies evaluating this method show a field loss of 250 to 400 kilograms per hectare compared with a field loss of only 100 to 150 kilograms per hectare when harvesting is done with a combine.

DISEASES AND PESTS

Sixteen different diseases that are caused by pathogenic microorganisms have been identified. The diseases that occur with the greatest frequency are root rots caused by *Pythium* spp., *Macrophomina phaseolina*, *Rhizoctonia solani*, *Sclerotinia sclerotiorum*, and *Fusarium* spp.; mildew (*Peronospora manchurica*); purple blotch (*Cercospora kikuchii*); frogeye leaf spot (*Cercospora sojina*); bacterial pustule (*Xanthomonas phaseolis* var. *sojense*); fire blight or bacteriosis (*Pseudomonas glycinea*); soybean mosaic; yellow mosaic; micoplasm; gill nematode (*Meloidogyne* spp.); and reniform nematode (*Rotylenchus* spp.). However, these diseases are not considered as limiting factors in soybean production.

Forty different species of insects and mites that are harmful to soybean plants have been identified in Colombia. *Anticarsia gemmatalis* Hubner is the most serious insect problem. Occasionally, some attack on pods by *Heliothis virescens* (F) and chinch bug, *Piezodorus guildinii* (Westwood), have been experienced. The latter could become a problem. Dry conditions and the presence of host weeds could favor infestations of *Diabrotica balteata* Le Conte and *Ceratoma ruficornis* Oliver, which could become a problem during the first 20 days after soybean emergence.

Insects that are considered to be of secondary importance in Colombia are: *Hedylepta indicata* (f), *Pseudoplusia includens* (Walker), *Trichoplusia ni* (Hubner), *Estigmene acrea* (Drury), and *Semiothisa abydata* (Guenee), which are all foliage feeders. There are also mites (*Tetranychus* spp.), and some species of worms (*Spodoptera* spp., *Agrotis ipsilon*, and *Conoserus* spp.). In addition, there are some potential pests that could become a serious problem, especially because they are associated with disease. Sucking insects such as white fly, *Bemicia tabaci* (Glennadius), cause yellow mosaic, and grasshoppers, *Scaphytopius fuliginosus* (Osborn), cause leaf blotching. There are also grubs, *Elasmopalpus lignosellus*, that attack young plants and can cause serious crop losses, especially during dry periods and particularly on sandy soils.

SEED PRODUCTION

The Investigation Program is in charge of producing breeder seed. There is also the ICA (Columbian Agricultural Institute) Seed Certification Program that controls the dealers, the production, and the quality of certified seed sold to soybean growers. Certified seed is produced and sold by one government-controlled company and six private companies.

IRRIGATION FOR SOYBEAN PRODUCTION

With supplementary irrigation, the average soybean yield in the Cauca Valley

is 2.5 metric tons per hectare. The ICA Experimental Centers have obtained commercial yields of up to 2.8 metric tons per hectare with supplementary irrigation, and up to 3.8 metric tons per hectare in experimental plots. Four metric tons per hectare is the potential average for the area that is presently producing soybeans.

PRODUCTION COSTS

Production costs per hectare are 22,000 Colombian Pesos for soybeans, 25,000 pesos for corn, 18,000 pesos for sorghum, and 45,000 pesos for cotton. These costs, and the price paid to the grower (18,000 Colombian Pesos per metric ton), make soybeans competitive compared with other crops.

FACTORS THAT LIMIT PRODUCTION

Although diseases are not considered a limiting factor in soybean production, research on disease resistance and the study of the diseases themselves should be increased. Management practices, such as the timing and application of supplementary irrigation and adequate harvesting methods, are still not well defined and these affect plant growth and yield. Land prices, soil preparation, and labor costs are also factors that affect production. The cost of the labor, which in some cases has increased by 150 percent, has had a great impact on production. Although commercialization does not present any particular problems, domestic soybean demand is directly related to the production of meal and oil from other sources (vegetable and animal), which in turn depends on the demand for food concentrates for the production of eggs, meat, and milk.

PUBLICATIONS OF THE GRAIN LEGUME AND ANNUAL OILSEEDS PROGRAM, INSTITUTO COLOMBIANO AGROPECUARIO (ICA), PALMIRA, COLOMBIA

- Effects of population density of some agronomic and physiologic characteristics of three soybean genotypes under tropical conditions.
- Foliage feeding insects in soybeans.
- Soybean reaction to application of Tri-iodobenzoic acid.
- Identification of physiological races of *Peronospora manchurica* (Naoum) found in the Cauca Valley and trial for variety resistance to soybean mildew.
- Studies on yield stability of 16 soybean homozygous lines.
- Production potential of various soybean genotypes under tropical conditions.
- Deflowering effects on behavior and productivity of soybeans.
- Methods to estimate foliage area in two soybean varieties with different population densities at four stages of growth.
- Interrelation of several agronomic characteristics of 20 soybean varieties.
- Study on row width and density at planting in one medium size soybean variety conducted at the Palmira National Agriculture Investigation Center.
- Effectiveness of some fungicides to control soybean mildew caused by *Peronospera manchurica* (Naoum).
- Breeding soybeans for tropical conditions.
- Natural deflowering of soybean on the Cauca River Valley conditions.
- Effect of plant population on yield components and other soybean characteristics.

ORGANIZATION

The Ministry of Agriculture is the organization responsible for the development of agriculture in Colombia. The Colombian Agricultural Institute (ICA), which is appointed by the Ministry of Agriculture, is the organization responsible for all agricultural research. Within the ICA there are various research programs such as the Grain and Annual Legume and Oilseed Program, which, in addition to soybeans, is responsible for beans (*Phaseolus vulgaris*, *Vigna unguiculata*, *V. angularis*, and *V. radiata*), peas (*Pisum sativum*), peanuts (*Archis hipogaea*), sesame (*Sesamum indicum*), and sunflowers (*Helianthus annus*). The programs are coordinated with the Soybean Growers Federation, processors, soybean seed producers, universities, and several government agencies on a national

level. Research is also done at the international level in cooperation with the International Soybean Program (INTSOY) and the International Center for Tropical Agriculture (CIAT).

Soybean research in Colombia is conducted at four experiment centers that are located at Palmira, Nataima, Turipana, and Hotilonia. These sites are representative of the present and potential soybean-producing areas. There are also laboratories and screen houses for research in different fields. There are 12 professionals presently working on research: one with a doctorate, four with master's degrees, and seven with bachelor of science degrees in Agronomy. To continue adequate research in potential soybean-growing areas during the next 10 years, 20 research professionals will be needed. Ten of them should specialize in different research disciplines.

Irrigated Soybean Production in Egypt

A.A. AZIZ, A.M. NASSIB, AND M.H. EL-SHERBEENY

SOYBEANS (*GLYCINE MAX* L.), ONE OF THE WORLD'S oldest cultivated crops, are attracting attention in many areas in the world. In Egypt, experimental plantings of soybeans were started 30 years ago; however, research activities have been intensified over the past 15 years, especially in the improvement of varieties and agronomic techniques. The crop has been produced commercially in Egypt since 1974, when 1,713 hectares of soybeans were grown, and the area under soybean production has increased 20 times in five years. During the same period, the average yield increased from 0.775 ton per hectare to 2.296 tons per hectare (Table 1). In 1978, about 51 percent of the total soybean acreage was grown in the Delta, 38 percent in Middle Egypt, and 11 percent in Upper Egypt.

Of the 12 soybean-producing governorates, Dakahlia, Gharbia, and Beheira in the Delta, and Minia and Beni-Suef in Middle Egypt had 74.2 percent of the total planted acreage and produced 72.6 percent of the soybean crop. The highest average yields were recorded in the Gharbia, Menufia, and Beheira governorates with 3.06, 3.05, and 2.96 tons per hectare, respectively.

Soybeans are grown as a summer crop following Berseem clover and other early winter crops such as broad beans, lentils, barley, onions, and other vegetables. It must compete for acreage with other summer crops, particularly cotton, maize, and rice.

Soybeans are grown mainly for oil and meal. Soybean oil represents about 4 percent of the annual consumption of edible vegetable oils (340,000 tons) in Egypt, while cottonseed oil supplies about 25 percent. The deficit is made up by imported oil. All the soybean meal produced in Egypt is used for poultry feed and the country's requirements were almost met in 1978.

A recent study showed that in 1978 the edible vegetable-oil requirements of Egypt were approximately 500,000 tons. Assuming that the production of cottonseed remained constant, and that the deficit in edible vegetable oil was met by soybean production, the crop acreage required, at a production level of 2.38 tons per hectare, would have been either 77,000 or 152,000 hectares depending on whether a 26.5 or 33.3 food security index* was targeted.

DEVELOPMENT OF VARIETIES

Egypt is located between latitudes 22° and 32° N and longitudes 24° and 37° E. The elevation ranges from 132.5 meters at Aswan to 1.5 meters at Damietta, on the Mediterranean. Egypt has warm, rainy winters and dry, hot summers that extend from April through October. In the Delta, maximum temperatures are between 32° and 35° C and minimum temperatures are between 19° and 21° C. In Upper Egypt, maximum temperatures range from 36° to 42° C, while minimum temperatures are from 20° to 26° C.

The current varietal development program is based mainly on the systematic evaluation of soybean varieties from other countries. Through 1978, 99 varieties were of U.S. origin. About 200 varieties from Taiwan, India, China, the Philippine Islands, and Russia were tested but were not adapted to Egyptian conditions. Varieties from the U.S., which are sown at Giza (30° N) in mid-April, can be divided into five classes according to the date of maturity under Egyptian climatic conditions.

Class A: varieties in groups 00, 0, and I that mature very early (80 to 100 days)

Class B: varieties in groups II, III, and IV that mature early (110 to 130 days)

*Proportion of needs supplied from domestic production.

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Class C: varieties in groups V and VI that have a medium maturity (140 to 150 days).

Class D: varieties in groups VII and VIII that mature late (160 to 180 days).

Class E: varieties in group IX that mature very late (more than 190 days).

Planting earlier or later than mid-April increases or decreases the periods of maturity.

Very early varieties (Class A) and very late varieties (Class E) proved to be unproductive and did not adapt. Advanced yield trials, which were confined only to classes B, C, and D, showed that the early maturing varieties of groups III and IV adapt best to Egyptian climatic conditions when grown during April. Having a short growing season, these varieties fit into the intensive cropping system that is common in Egypt and require minimal control measures against cotton leaf worm (*Spodoptera littoralis* Boisd), which attacks severely during late June through July, when the soybeans are maturing.

Three short-season varieties, Clark, Williams, and Calland, produced high yields. All are being grown commercially at the present time. The yield data and agronomic characters for the best early performers during the three-year period from 1976 to 1978 are presented in Table 2.

Varieties in maturity groups V through VII have a prolonged growing period when planted late when compared with varieties in groups II through IV. The former varieties possess a high yield potential when planted after mid-May. The short growing period of early maturing varieties is detrimental to these varieties. Medium- and late-maturing varieties have a place in the rotation and are sown on considerable acreage after the wheat harvest. However, the high costs of controlling cotton leaf worm are a limiting factor in late sowing. Evolving resistant varieties against this pest is a measure that should be considered in the future. Among the medium- and late-maturing varieties, Forrest, Essex, Dare, Lee-68, and Ransom produced high yields.

Seed Production

A program for maintaining and distributing released varieties is being carried out. The Food Grain Legume Research Section of the Agricultural Research Centre takes care of the breeder's foundation and registered seed at the farms of the Ministry of Agriculture. The Seed Department, which is under the Ministry of Agriculture, is responsible for producing, inspecting, testing, and distributing certified seed to farmers.

PRODUCTION AGRONOMY

Adaptive Soils

Although the best soybean yields are on well-drained, deep, fertile loam soils, satisfactory results can be obtained on a fairly wide range of soils. However, sandy soils tend to dry out rapidly and are not recommended for soybean production.

Seedbed Preparation

A fine, firm seedbed is important to ensure uniform stands. Land preparation, which is two ploughings followed by two or more harrowings, is done with either tractors or animals.

Sowing Methods

Sowing is a critical operation in growing soybeans, and crop failures can often be traced back to errors in the choice of sowing methods.

In Egypt, three methods are used to sow soybeans. In the *herati* method, the soil is irrigated and a few days later the seeds are planted in moderately moist soil. This method produces a large, uniform stand. The seeds are planted in dry soil in the *afir* method, and the soil is irrigated immediately after sowing. In the *improved afir* method, the soil is irrigated to make it firm and left to dry for a few days. The seeds are planted in the dry, firm soil, which is irrigated immediately after sowing. Improved afir produces better seedling emergence than afir but herati still gives the best results. In all cases, the seeds are planted on ridges, either in hills or by drilling. The depth of seeding is an important consideration. Planting at a depth of 3 to 4 centimeters is ideal. Deeper planting has an adverse effect on the stand.

The soil surface often crusts over between planting and emergence, particularly in the calcareous soils of the newly reclaimed fields at Nubaria, which are 25 to 30 percent $CaCO_3$. In areas where crust formation adversely affects germination and seedling emergence, seeding on ridges using the herati method, and irrigating lightly once or twice after planting at seven-day intervals has been effective.

Rate of Seeding and Population Density

Nearly all soybeans in Egypt are planted on ridges and require manual planting, weeding, furrow irrigation and other agronomic operations.

Seeding rates between 30 and 40 kg/feddan* are practiced, giving a population of about 140,000 plants per feddan (33 to 35 plants per square meter). This plant population is achieved by drilling at the recommended seeding rate on one side of the ridges, 60 centimeters apart.

Several row spacing experiments were conducted during the period from 1975 through 1978. Row spacing treatments ranging from 30 centimeters to 70 centimeters were investigated. The level of significance among the treatments varied but the trends were similar during the entire period. Narrow spacing gave higher yields than wide spacing. In most of the experiments, where 35 centimeter and 60 centimeter row widths were studied, the narrow spacing produced significantly larger yields than the wide spacing (Table 5).

Sultan (1978) obtained an increase in seed yield by increasing the rate of seeding up to 45 kg per feddan. Mohamed (1977) reported that decreasing the row width and the hill spacing and increasing the number of plants per hill significantly increased seed yield.

Farmers are advised to plant the soybeans on ridges 70 centimeters apart, to drill on both sides of the ridge, and to use a seed rate of 40 to 45 kilograms per feddan. However, the use of narrow rows means using herbicides to control weeds since cultivation is difficult in narrow rows.

Date of Sowing

The planting date is considered to be one of the most critical cultural practices in the production of soybeans since it affects the length of the various stages of growth and the amount of growth in each stage. However, the farmers plant soybeans over a period that extends from mid-March to late June, depending on when the fields of the preceeding crop had been harvested.

Several studies have been carried out to investigate the optimum planting date, emphasizing the short-season varieties, Clark, Williams, and Calland, that are currently used in the area planted to soybeans in Egypt.

The results indicate that the maximum yields were obtained from seeds sown during April. Planting soybeans later than mid-May resulted in a significant decrease in seed yield (Table 4).

Recent studies on the effects of the date of planting on early to late-maturing varieties indicated that early maturing varieties (groups II, III, and IV) responded well to earlier planting dates while medium- and late-maturing varieties (groups V through VII) gave their highest yields when sown on May 15 (Table 4).

From previous studies and under the intensive cropping system of Egypt, planting short-season varieties during April can be considered as an effective and economic method for maximizing the yield of soybeans and for reducing the damage caused by cotton leaf worm. In addition, this method would reduce production costs and enable farmers to grow early hybrid corn, a late summer crop, after the soybeans are harvested.

Water Management

All soybeans in Egypt are grown under irrigation but the information available about the water requirements of soybeans is still scarce. At present, about six irrigations at 15-day intervals are recommended, but more soil moisture seems to be necessary. Recently, El-Wakeel (1979) studied the effect of different irrigation regimes on soybean production at the Bahteem Research Station, which has a loamy, clay soil. He concluded that the highest seed yield per unit area was obtained when irrigation took place at 40-percent depletion of available soil moisture. The next best results were obtained when irrigation took place at 60-percent depletion. Irrigation at 80-percent depletion of available soil moisture resulted in the lowest yield. The three depletion levels were reached at one-, two-, and three-week irrigation intervals.

Fertilizer Use and Inoculation

Egyptian soils are devoid of *Rhizobium japonicum*. In field experiments, nodulation can be ensured if the correct measures are taken. In farmers' fields, nodulation has been inconsistent and efforts are currently under way to correct this situation.

At present, in the absence of successful root nodulation, 60 kilograms of nitrogen per feddan, added as a side dressing in three doses at 15-day intervals after sowing, is recommended. This may not be adequate to get the highest soybean yields on soils that

*One feddan equals 4,200 square meters.

lack *Rhizobia*. Experimental results revealed that successful inoculation gives significant increases in seed yield, 100 seed weight, and harvest index; a high rate of nitrogen applied to inoculated plants produced insignificant increases in yield while leading to decreased nodulation. Uninoculated plants responded to nitrogen application. The responses were linear up to 100 kilograms per feddan at Bahteem and up to 160 kilgorams per feddan at Nubaria (newly reclaimed soils), which suggests that an application of 100 to 160 kilograms of nitrogen per feddan may have to be added to counteract the nodulation failure that frequently occurs.

Phosphorus and potassium are the two fertilizer nutrients that have been recommended. They should be applied at the rates of 15 kilograms of P_2O_5 and 24 kilograms of K_2O per feddan. Both fertilizers are usually broadcast during seedbed preparation.

Weed Control

Manual cultivation is the only method commonly used for controlling weeds. In order to keep the field clean, cultivation must be repeated two or three times. Cultivation should be shallow so that weed seeds are not brought to the surface and to avoid damaging the root system.

A preplant-incorporated application of Treflan 48 percent or Corbex 25 percent or a preemergence application of Stomp 32 percent was effective in controlling a wide range of grasses and broadleaf weeds.

Harvesting

Seed yield was significantly increased by delaying the harvest until 95 percent of the pods were ripe. Earlier harvesting resulted in lower yields and inferior seed quality.

The crop is generally harvested by hand and threshed with flails or sleds dragged through the harvested soybeans by oxen or tractors, but in some cases stationary threshers powered by gasoline motors are used. Even on large farms in the newly relaimed lands, soybeans are cut by hand and carried to stationary combines or threshers.

Intercropping

Intercropping soybeans with corn, sorghum, cotton, or sugarcane may be of considerable importance in expanding the acreage of soybeans under the intensive cropping system of Egypt.

Several studies were carried out on intercropping soybeans with corn. The results indicated that the yield of grain corn and soybean seed were generally decreased by intercropping when compared with solid plantings from each crop. On the other hand, the yield of grain corn and soybean seed under different intercropping systems resulted in different increases ranging from 10 to 32 percent per unit area, over the solid plantings of each crop. However, intercropping soybeans is still in the experimental stage. The practice is not yet common among farmers.

Diseases and Insects

A large number of fungi, including *Pythium* spp., *Fusarium* spp., *Rhizoctonia* spp., and *Macrophomina* spp., attack germinating seeds and seedlings and cause a loss in stand. Treating seed with fungicides protects the seedlings from rots and results in improved stands.

Cotton leaf worm (*Spodoptera littoralis* Boisd) and common red spider (*Tetragchus telarius* L.) are the two major pests that affect soybeans in Egypt. The two pests can be controlled by the proper timing of insecticides. Cutworm, greenbug, bean fly, and mole crickets also infest the crop but are of minor importance.

Economics of Crop Production

Under an intensive cropping system, farmers can grow two or three crops per calendar year. The average cropping ratio is 1.9. Most materials for agricultural production are supplied to the farmers at subsidized rates. Meanwhile, the farmers' prices for major crops are determined by the government. The farm price offered for soybeans is L.E. 200* per ton.

Net returns from soybeans alone or in an annual rotation (Table 7) are higher than for any other crop or rotation.

A farmer growing Berseem clover in the winter (two cuts), then soybeans and, late in the summer, planting early hybrid corn, can receive a net return of a relative value of 100 percent compared with 58.29 percent for a rotation of clover and cotton, 57.42 percent for clover and corn, and 21.22 percent for wheat and corn.

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*L.E. (Egyptian pound) equals $1.42.

PRODUCTION CONSTRAINTS

1. Damage from cotton leaf worm is probably the most serious limiting factor.

2. Achieving adequate nodulation is inconsistent.

3. The development of more efficient and productive soybean varieties that are resistant to feeding by cotton leaf worm is necessary.

4. Adequate farm machinery necessary for timely land preparation, weeding, and harvesting is lacking.

5. Competition for land with the other summer crops restricts the area where soybeans can be grown, especially in established growing areas. Major production should come from new lands. Investigating soil problems, developing adapted varieties, and adopting a mechanized farming system and production technology appropriate to these lands are of major importance.

ORGANIZATION

A soybean national development program has been undertaken by the Ministry of Agriculture. Research on problems relating directly to the farmers is carried out in the institutes of the Agricultural Research Centre, through coordination between different disciplines, for example, food legume breeding and agronomy, plant nutrition, soil microbiology, plant pathology, entomology, water requirements, and weed control. The Extension Service of the Ministry of Agriculture brings the results of this research to farmers in the form of recommendations for better cultural practices. The Seed Department in the same ministry is concerned with the production and distribution of certified seed.

A soybean council (Ministry of Agriculture) has been operating since 1972. The main responsibilities of this council are suggesting national policy and planning the development of soybean production and use in Egypt.

The professors and graduate students in the faculties of agriculture at various universities and the staff of the National Research Centre frequently contribute to applied research on soybeans.

The Agricultural Research Centre has its central experiment station at Giza. Ten substations with field equipment, routine fields, and laboratory supplies are located in the major agronomic zones. At the present time, the staff working on soybean research consists of 6 staff members with Ph.D. degrees, 8 with M.Sc. degrees, and 15 with B.Sc. degrees.

Training in the fields of agronomy, breeding, and the inoculation of soybeans with *Rhizobium* will be required at the M.Sc. and Ph.D. levels during the next 10 years.

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Table 1. Soybean Area, Production, and Average Yield (tons per hectare) in the Three Agro-Ecological Regions of Egypt, 1974-1978

	Delta			Middle Egypt			Upper Egypt			Total			
											Yield		
Year	Area (ha)	Yield (ton/ha)	Prod. (tons)	Area (ha)	Yield (ton/ha)	Prod. (tons)	Area (ha)	Yield (ton/ha)	Prod. (tons)	Area (ha)	ton/ha	index	Prod. (tons)
1974	335	0.838	281	1,345	0.752	1,011	33	1.121	37	1,713	0.775	100	1,329
1975	1,213	0.928	1,126	2,028	1.230	2,494	266	0.864	230	3,507	1.098	142	3,850
1976	2,489	1.790	4,455	3,829	1.502	5,751	595	1.204	716	6,913	1.580	204	10,922
1977	6,626	2.009	13,312	6,049	1.580	9,557	772	1.633	1,261	13,447	1.794	231	24,130
1978	17,495	2.577	45,085	13,216	1.894	25,031	3,702	2.406	8,907	34,413	2.296	296	79,023

Table 2. Average Seed Yield (tons per hectare) and Other Agronomic Characters of the Six Top-Yielding, Early Maturing Varieties Compared with the Check Variety, Harosoy

	Yield (tons/ha)				Agronomic characters			
					Days to		Plant	
Variety	1976	1977	1978	Mean	flowering	maturity	height (cm)	100-seed weight
Columbus	2.371	4.787	3.757	3.638	44	128	84.20	14.98
Calland	1.867	4.134	3.342	3.114	42	118	76.75	16.78
Clark	2.336	3.652	3.166	3.051	44	120	80.33	16.45
Williams	2.245	3.417	3.002	2.888	42	116	68.25	15.43
Bonus	1.838	3.849	2.859	2.848	44	119	82.50	16.35
Cutler	2.013	3.546	2.846	2.802	43	121	88.75	16.83
Harosoy	1.649	3.222	2.497	2.456	42	110	65.75	15.43

Note: The results in the table represent combined data of different locations in the different years.

Table 3. Effect of Planting Date on Seed Yield of Four Early Maturing Varieties of Soybean (Summary of 1977 and 1978 Results)

Planting	Yield (tons/ha)				
date	Clark	Calland	Williams	Columbus	Mean
Mar. 15	3.294	1.976	3.291	1.704	2.566
Apr. 1	3.409	2.049	3.919	1.736	2.778
Apr. 15	3.562	1.860	3.375	3.770	3.142
May 1	3.005	2.014	2.995	2.874	2.781
May 15	2.880	1.779	3.035	2.652	2.586
June 1	2.671	1.446	2.554	1.886	2.139

Table 4. Average Yield (tons per hectare) and Days to Maturity of Soybean Varieties in Maturity Groups as Affected by Planting Date, Giza, 1977

Maturity	Number of	Yield (tons/ha)			Days to maturity		
group	varieties	Mar. 15	Apr. 15	May 15	Mar. 15	Apr. 15	May 15
I and II	6	2.970	3.856	2.786	111	110	103
III and IV	8	3.746	4.802	3.713	134	128	116
V and VI	5	3.067	3.078	4.180	176	168	142
VII	3	1.327	1.753	3.437	188	179	158

Table 5. Effect of Row Spacing on Seed Yield of Four Early Maturing Varieties of Soybeans (Average 1977 and 1978 Seasons)

Row spacing	Population density	Yield (tons/ha)				
(centimeters)	(square meters)	Clark	Williams	Calland	Columbus	Mean
35	50 to 55	3.251	3.544	2.248	3.251	3.133
60	30 to 35	3.063	2.841	1.945	3.063	2.726

*Table 6. Comparative Returns and Costs of Alternative Annual Crop Rotations Based on 1977 Costs and Prices (L.E)**

Crop rotation	Production		Net return		Percent of soybean rotation
	Value	Cost	Crop	Rotation	
Wheat	91.90	75.80	16.10		
Corn	93.17	70.97	22.20		
Total				38.30	21.22
Catch crop clover	66.96	15.79	51.17		
Cotton	176.82	122.80	54.02		
Total				105.19	58.29
Full-term clover	133.92	52.51	81.41		
Corn	93.17	70.97	22.20		
Total				103.61	57.42
Lentils	92.68	69.00	23.68		
Corn	93.17	70.97	22.20		
Total				45.88	25.42
Clover (2 cuts)	66.96	15.79	51.17		
Soybean	200.00	90.00	110.00		
Early hybrid corn	87.79	68.52	19.27		
Total				180.44	100

*L.E. (Egyptian pound) equals $1.42.

Irrigated Soybean Production in Ethiopia

A. MENGISTU

IN ETHIOPIA EMPHASIS IS NOW BEING GIVEN to the cultivation of protein rich crops. Soybeans (*Glycine max* (L.) Merr.) are one of these crops and have been given a high priority.

Soybeans were first introduced into Ethiopia in 1950 but trials were discontinued because yields were low. With the introduction of high yielding cultivars in the 1970's, new interest was generated. Many of the new cultivars introduced into Ethiopia have come from Europe and the United States. The cultivation of soybeans has become important because:

1. Soybeans contain a higher percentage of protein and oil than other pulse crops grown in Ethiopia and can be used to upgrade the peasants' diet;
2. Soybeans grown in Ethiopia can reduce the amount of soybean flour now imported for the making of "faffa" (a children's food);
3. Ethiopia may be able to export soybeans if they can be sucessfully grown.

At present about 2,000 hectares of land are under production by the State Farms Development Authority, which is only 10 percent of the amount required by the Ethiopian Nutrition Institute (ENI).

In Ethiopia, the Ethiopian Nutrition Institute's supplementary food program is the sole user of soybeans. Processing machinery in now available and the processing of soy flour has begun, which will undoubtedly increase the demand for locally produced soybeans.

Efforts are being made to introduce soybeans into the diet of the farmers through women extension agents. Farmers' wives are being taught how to prepare soybeans and to fit them into the local diet and food habits.

Soybeans are better adapted to a sandy loam soil than a black clay soil because light soil provides better drainage and is more easily cultivated than black clay soil. In the production fields, sowing is done by broadcasting the seeds by hand at the rate of 70 kilograms per hectare. Yields obtained from these fields are usually from 1 to 1.3 metric tons per hectare. The best yielding varieties are Davis, Coker 240, and Protana, which give yields of 37, 32, and 30 quintals per hectare, respectively, under experimental conditions. The planting of soybeans begins in early June and they mature in about 130 days at altitudes of 1,250 to 1,400 meters. At this altitude yields per hectare are higher and maturation is shorter than for soybeans grown above 1,600 meters. It takes from 140 to 160 days, depending on the variety, for soybean cultivars to mature at 1,860 meters. Didessa at 1,300 meters and Anger Gutin at 1,400 meters, both located in western Ethiopia, have been found to be the best locations for soybean production. Moisture during the vegetation period in these areas is about 1,000 millimeters and no supplemental irrigation is needed. With large scale production, threshing has been done by running a tractor over heaps of harvested beans.

Studies of inoculation with *Rhizobium* bacteria conducted about five years ago did not show a significant effect on yield. However, we are now cooperating with INTSOY to the evaluate the status of soybean nodulation to determine whether inoculating soybeans with *Rhizobium japonicum* is essential or whether this bacterial strain is present in the soil. Applications of P_2O_5 at planting using 40 to 50 kilograms per hectare has shown very good results where soil phosphorus is low. A spacing of 40 centimeters between rows and a seeding rate of 70 kilograms per hectare have been found to give good stands and high yields.

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Only a few reports have been recorded of soybean diseases in Ethiopia. The first report of soybean disease was made by Stewart in 1957. He reported a leaf spot, *Pyrenochaeta glycines*. Other disease-causing fungi and bacteria found to be associated with soybeans are *Ascochyta* spp, *Macrophomina phasealina*, *Mycosphaerella cruenta*, *Pseudomonas glycinea*, *Xanthamonas phasedi*, *Perenospora manchurica*, *Cercospora kukuchi*, soybean mosaic virus, *Diaporthe phaseolorum* var *sojae*, and several seed-borne pathogens. Of all these diseases, *Pseudomonas glycinea*, the causal organism of bacterial blight, has been found to be the most serious, yield-limiting factor and our varietal screening is concentrated on selecting lines resistant to this disease.

Insect pests are not a problem at present. However, pests like spider mites and cutworms have been reported.

The possibilities of growing soybean under irrigated conditions are great, especially in the Awash River Valley. Here the major crop is cotton, which is irrigated. Soybeans can be produced here in rotation with cotton.

Irrigated Soybean Production in Sri Lanka

H. GAMAGE

SOYBEANS WERE FIRST INTRODUCED TO SRI LANKA a few decades ago, but only became a priority crop in the early 1970's. Research conducted so far has shown that soybeans can be grown successfully in the dry zone and the intermediate zone of the country under both rain-fed and irrigated conditions. In these zones, soybeans are grown as a monoculture. In the wet zone, soybeans are intercropped with coconut. Excess rainfall in the wet zone has been a limitation in profitable soybean cultivation.

Soybean foods are foreign to Sri Lankans. Successful development of foods made from soybeans that suit the local palate will enhance the demand for soybeans and farmers' interest in growing the crop.

PRODUCTION TECHNOLOGY

Area Under Soybean Production

The area brought under soybean cultivation and production in Sri Lanka from 1974 to 1978 is shown in Table 1. One year's production includes soybeans grown in both the Maha (wet season) and the Yala (dry season). Approximately two thirds of the hectarage each year is grown in the Maha and one third in the Yala.

Table 1. Annual Production of Soybeans in Sri Lanka

Year	Area in hectares	Production in metric tons
1974	1,293	980
1975	1,127	1,135
1976	712	615
1977	1,001	1,098
1978	1,903	2,426

Cultural Practices and Cropping Patterns

Timing is a prerequisite for successful soybean cultivation in the dry and intermediate zones. Land preparation for rain-fed soybean cultivation has to begin immediately after the few showers that occur in late September. There is a short dry spell of two to three weeks after these rains when land preparation can be carried out. The availability of sufficient power to work the soil during such a short period is the main limiting factor in land preparation, which must be carried out when the soil is at the right moisture level. The reddish brown earth that covers the major part of the dry and intermediate zones has a very narrow moisture range for successful planting. The soil is sticky when wet and very hard when dry.

The land is worked to a good tilth with animal or tractor-drawn implements. If tractor power is not available, the ordinary country plough, drawn by water buffalo, is the commonly used implement for tilling the soil. The spiked-tooth tinetiller is used with the tractor. After leveling, planting is done in flat or furrowed basins. Water stagnation in low pockets is a common problem in the flat basin system. Making furrows constructed between the rows at the time of the first weeding eliminates this problem.

Even though the furrowed basin method provides better drainage, it is more labor intensive than the flat basin method because of the extra labor used in constructing furrows and the difficulty of weeding on the ridges.

Of the commonly grown soybean varieties, an average of 70 to 90 kilograms per hectare are used for planting. The optimum plant density is about 450,000 plants per hectare. The recommended spacing is 45 centimeters between rows and 5 to 7 centimeters within the row at a seeding depth of 3 to 4 centimeters.

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Varieties and Fertilizer Used

Varieties used in commercial production have been introduced from other countries. The varieties Pb-1, Bossier, Improved Pelican, Davis, Hardee, and SJ-2 have been grown. Pb-1 is more popular than the other varieties because it has superior seed quality.

A basal application of fertilizer consisting of 22 kilograms per hectare of nitrogen in the form of ammonium sulfate, 67 kilograms per hectare of phosphorus in the form of superphosphate, and 45 kilograms per hectare of potassium in the form of muriate of potash is recommended and commonly used. Two topdressings of nitrogen three and six weeks after planting at the rate of 60 kilograms per hectare of ammonium sulfate are applied when the seeds have not been inoculated. The inoculated seeds need only the basal application referred to above.

Imported NITRAGIN is the only inoculum used and is highly effective under local conditions. The Sri Lanka Soybean Development Project is interested in producing inoculum locally, but finding a suitable local raw material to culture the rhizobia remains a problem. Coconut shell powder is being tested as a possible carrier.

Irrigation

Soybeans have been recommended for well-drained soils on irrigated land where the natural water table is deep, but only a few farmers choose soybeans instead of rice. In the Maha season (October to February), irrigation water is supplied to supplement the rainfall during short dry spells. During this season, adequate drainage facilities must be provided. To overcome this problem, the furrowed basin system is recommended. Soybeans are grown in Yala (March to July) only under irrigation. Yala plantings are made from mid-April to early May.

On well-developed land, furrow irrigation has been practiced. Furrow lengths of 150 to 200 feet are recommended on a 0.4 percent slope for stream sizes of 10 to 15 gallons per minute. On moderately well-developed land, flat or furrowed basin irrigation is recommended. Basin irrigation is commonly practiced when soybeans are planted in paddy fields in the Yala season. On the reddish brown earth on the dry zone, soybeans have been grown successfully on well-drained and poorly drained soils. However, the yields on poorly drained soils are not attractive. When compared with other pulse crops, soybeans have performed well on both types of soil (Table 2).

Table 2. Yield Performance of Crops on Well-Drained and Poorly Drained Soils

Crop	Well-drained soils	Poorly drained soils
	kilograms per hectare	
Soybeans	933	730
Ground nut	913	234
Black gram	748	561
Green gram	885	..

Soybeans are irrigated at 75 percent depletion of available moisture on well-drained land. Water is applied once every 4 to 5 days during the first month and once in 7 to 10 days thereafter. The soil is wetted 1 to 2 feet in the first month and and increased to 3 feet afterwards. The peak consumption per day is about 7 millimeters. If the crop is irrigated, about 10 irrigations are required. On well-drained land, the water requirement is 70 to 80 centimeters. The plants must not be exposed to severe stress during the flowering and bean-filling stages. Moisture stress can result in flower abortion and unfilled, shrivelled seeds. Yield reductions can be as high as 60 to 70 percent.

Plant Protection

No serious outbreaks of insect pests or diseases have been recorded. Yellow mosaic virus, soybean mosaic virus, purple seed stain, and bacterial pustule are present but not serious.

Seed Production

The government's seed-production program has been organized as follows. The regional research stations produce breeder seed. This seed is turned over to the government seed farms, which are managed by the Department of Agriculture, to produce foundation seed. Foundation seed is supplied to certified seed growers through the extension division of the Department of Agriculture. The seed-production target for 1978-79 (Maha and Yala) was 284,000 kg. Government seed-production farms have been equipped with seed-processing plants and storage facilities. Seed certification is carried out by two state-owned seed laboratories. The viability of seeds can be adequately maintained because Sri Lanka has two growing seasons. Seed from one season can be planted in the next season.

Yields with Irrigated Soybeans

Frequently irrigated soybeans yield almost twice as much as rain-fed crops. Under research station conditions, a rain-fed crop yields 2,500 to 2,750 kilograms per hectare while an irrigated crop produces 4,000 to 4,200 kilograms per hectare. In the farmer's fields, a rain-fed crop averages 1,100 to 1,700 kilograms per hectare, and an irrigated crop yields 2,250 to 2,850 kilograms per hectare. Whether irrigated or rain-fed, soybeans yield more than all other legume crops.

Cost of Production

The cost of production has increased rapidly during the last few years. In 1973, the cost of production was about Rs. 1,500 per hectare[1] whereas the present cost is about Rs. 3,000 per hectare.[2] The increased cost of production is offset by the higher price offered for the soybeans; therefore, the increased cost of production is not a constraint to the farmer. In 1973, the price of soybeans was Rs. 2.00 per kilogram (Rs. .90 per pound) but the government now offers Rs. 5.50 per kilogram (Rs. 2.50 per pound).

Constraints

The major constraints in irrigated soybean cultivation in Sri Lanka are not agronomic. Constraints are from poor marketing facilities. Compared with other legume crops, soybeans are the easiest to grow with fewer problems from pests and diseases. Soybeans grow well on all types of soil. However, soybean foods are foreign to Sri Lankans. To establish a true and steady price for this commodity, either soybeans must find a market outside Sri Lanka or the Sri Lankans must be persuaded to use soybeans as a supplement for their present food supplies. To include soybeans in our normal diet is not easy. The traditional foods made from soybeans that are associated with the use of bacteria and fungi (fermented foods) do not appeal to Sri Lankans, but foods acceptable to the local palate are being developed. A Soybean Foods Research Centre, for research and product development, has been established by the Department of Agriculture.

[1]Equalled $8.00 in 1973 dollars.
[2]Equalled $15.50 in 1979 dollars.

ORGANIZATION

Structure

The promotion of soybeans in Sri Lanka began in 1973 by the Department of Agriculture, Ministry of Agricultural Development and Research, in the collaboration with the International Soybean Program (INTSOY). Sine 1975, the programs has been assisted by UNDP, FAO, CARE, and UNICEF. The soybean program in Sri Lanka has been named the Sri Lanka Soybean Development Programme. This organization has been responsible for the development of a balanced soybean industry including production, marketing, processing, and use. The research component consists of agronomic practices such as weed, insect, and disease control; water management; and soy-based food processing for local consumption. The Sri Lanka Soybean Development Programme has established a Soybean Foods Research Centre that is involved in research, product development, training, extension, and demonstrations at the home, village, and commercial levels.

A soybean committee in the Department of Agriculture provides policy guidance and program review.

Recently, the government appointed a National Soybean Committee, which is an interministerial body with participation from the private sector, to determine the national policy on soybeans and to study all matters connected with the production, processing, pricing, and marketing of this commodity.

Research Facilities

Forty-two part- and full-time soybean workers constitute the Sri Lankan staff under the leadership of a soybean coordinator. Two INTSOY staff members reside in Sri Lanka. Short-term consultants provide additional support. Production research is conducted at two main research stations and up to eight substations. As previously indicated, the Soybean Foods Research Centre is an excellent facility for processing and using soybeans.

Irrigated Soybean Production in the Sudan

O. A. A. AGEEB AND F.M. KHALIFA

SUDAN LIES BETWEEN latitudes 4° and 22°N and longitudes 22° and 38°E and has an area of about 2.5 million square kilometers--8.3 percent of the area of Africa. The population of the Sudan was about 17.5 million in 1973. Ninety percent of the working population (estimated at 6 million) are involved in agricultural production and animal husbandry. The cultivable land is estimated at 84 million hectares, but only 10 percent is being used. The irrigated area is 1.7 million hectares; the rest is rain-fed.

The region of greatest agricultural activity lies between latitudes 10° and 16°N with rainfall ranging from 150 millimeters at the northern boundary to 750 millimeters at the southern boundary. The rainy season is from July to September. The soils in this area are heavy, cracking montmorillonite clays, very low in organic matter and nitrogen, with a pH of 9.

Soybeans are not yet a commercial or a peasant crop in the Sudan. Research work is being done to establish the crop in the field in order to find its potential economic importance. Physically, the Sudan, with its enormous agricultural resources, has great potential for growing soybeans. Plenty of unused, agriculturally suitable land is available that could be easily developed under irrigation and rain-fed conditions.

The river Nile and its tributaries are the main sources of irrigation. The Sudan has not fully used its share of the Nile water, which could be used to double the present irrigated area. Canals are used for irrigation, which make use of the flatness and gentle slope of the land.

Soybean development in the existing irrigated schemes could only take place at the expense of another crop in the rotation. The fallow land in the Gezira rotation cannot presently be cropped because the canals now carry their full capacity of water to the existing cropping pattern; the canals can only irrigate 0.42 million hectares at one time. Wheat is becoming a strategic and important food but the Sudan is not yet self-sufficient. Cotton and groundnuts are export crops and bring in needed hard currency. On the other hand, sorghum, which can be cheaply and plentifully produced under rain-fed conditions, could be replaced by soybeans if farmers are convinced that planting soybeans is in their interest. The growing area of sorghum is 150,000 hectares.

The Sudan is a large exporter of vegetable oil and oil seeds. Soybeans are looked on by planters as a crop for the future when diversifying crop production for export.

PRODUCTION TECHNOLOGY

Serious research in producing soybeans began seven years ago with varietal introductions from the U.S.A. and by the participation of the Sudan in the cooperative INTSOY varietal testing program. The following is a brief account of some research findings.

Varietal Testing

Soybean varieties were tested at the Gezira Research Station, Wad Medani, between 1973 and 1977 (Salih, 1977). The best yields were from Semmes and Williams, with Hardee as a close second (Table 1).

ISVEX trials were conducted at Wad Medani and Abu Naama in 1978. The best yield at Wad Medani was from Hardee LS (2.7 tons per hectare) followed by Jupiter and UFV-1, while at Abu Naama, UFV-1 ranked first followed by Caribe and Cobb (Table 2). The grain yields at Wad Medani were more than double those at Abu Naama, which could be the result of late sowing at Abu Naama.

Work is progressing to find the varieties that are best adapted and have good agronomic characters.

Osman A.A. Ageeb is Senior Agronomist (Soybean) at the Gezira Research Station, Wad Medani, Sudan, and Fathi M. Khalifa is an Agronomist (Oil Crops) at Kenana Research Station, Abu Naama, Sudan.

Seeding Time

Field trials at Abu Naama and Wad Medani indicated that early sowing in late May and early June resulted in better yields than later sowing (Table 3). At Abu Naama, the best yield resulted from the earliest sowing date (June 15) while at Wad Medani the optimum sowing date seemed to be between May 22 and June 5.

Plant Spacing, Row Spacing, and Seeding Rate

At Abu Naama and Wad Medani, the best row spacing was found to be the 60 centimeters used at Wad Medani (Table 4a). At Abu Naama, the best plant spacing was 5 centimeters (Table 4b). At Wad Medani, the optimum seeding rate seemed to be about 70 kilograms per hectare (Table 4c). Grain yield nearly doubled, increasing the seed rate from 23.8 to 71.4 kilograms per hectare. There was little or no increase in yield with higher rates up to the highest level tested (190 kilograms per hectare).

Fertilization and Inoculation

The clay soils of central Sudan are low in organic matter and nitrogen, have plenty of potassium, and are low in available phosphorus. All nonnodulating crops have a high response to nitrogen, no response to potassium, and an occasional response to phosphorus.

Field trials at Abu Naama and Wad Medani showed that soybeans had a high response to an application of nitrogen and to *Rhizobium* inoculation (Table 5a). *Rhizobium* inoculation resulted in a yield comparable to the application of 86 kilograms of nitrogen per hectare. An experiment on the rate of the commercial inoculum, NITRAGIN, on the grain yield of soybeans showed that for the granular form, the optimum rate was 5.56 kilograms per hectare, and for the powder, applications of 4 grams per kilogram of seed gave the highest yield (Table 5b).

There is no local production of *Rhizobium japonicum* inoculants, therefore the inoculum has to be imported.

Irrigation

The irrigation source is the Nile and the method of irrigation is surface flow. Research has not started on the water requirements of soybeans but will very soon. The water requirements of groundnuts, which are grown in the same season as soybeans and have a similar growing season (mid-June to October 10), is 590 millimeters (Fadle, 1976-77). Groundnuts are watered at intervals of 14 days.

Plant Protection

Bacterial pustule is the major disease in the field. Screening work is in progress in the pathology section to select varieties that are tolerant to disease. Blister beetle *(Epicanta aethiops)* is the major insect, causing great damage to the plant from the seedling stage to the reproductive stage, but it can be easily controlled by chemicals. The beetles feed on the epidermis of the leaves and skeletonize them. Other insects of importance are the Egyptian leaf worm *(Spodoptera littoralis)*, and the American bollworm *(Heliothis armigera)*.

ORGANIZATION

The soybean development program is under the Ministry of Agriculture and soybeans are considered to be an oil crop; however, no definite program has begun to promote the crop under irrigation. Recently, the World Bank furnished a loan to the Mechanized Farming Corporation to promote the crop under rain-fed conditions.

Research Facilities

Research on the crop is undertaken at three regional experimental stations (Wad Medani, Abu Naama, and Kadugli) and two outreach field stations (Samsam and Agadi). Research on irrigated soybeans is done at Wad Medani and Abu Naama, the rest of the research is on rain-fed soybeans.

Research facilities are lacking, especially laboratory equipment and plot-size machines (planters, drills, harvesters, and threshers). The technical manpower working on soybeans consists of a full-time agronomist with a Ph.D. working at Wad Medani, an agronomist with a Ph.D. working on oil crops at Abu Naama, and an agronomist with a Ph.D. working on a number of food and oil crops at Kadugli. In addition, a pathologist with a Ph.D. at Wad Medani, with a heavy commitment to pathology work on other crops, is carrying out disease surveys, seed viability tests, and seed dressing trials. A botanist at Wad Medani is screening herbicides for chemical weed control. An entomologist with a Ph.D. at Wad Medani is cooperating with the soybean program insect surveys, giving advice on control measures. He has also initiated a program on the identification of pests and their damage.

For the coming ten years, the following training is suggested for the soybean development program.

1. One microbiologist with a Ph.D.
2. Two agronomists with Ph.D.'s to develop a soybean program under rain-fed conditions.

3. One pathologist with a Ph.D. to work on bacterial pustule disease and seed viability.
4. One agricultural engineer with an M.Sc.
5. Two plant breeders (Ph.D.), one for irrigated and the other for rain-fed soybeans.
6. The training of 8 to 10 technicians at international research centers for 4 to 6 months.

LITERATURE CITED

Fadle, O.A.A. 1967-1977. Annual report of Gezira research station.

Salih, M.O.M. 1977. Summary of research work carried out in the Sudan on soybean. Paper presented to the Crop Husbandry Committee.

Table 3. The Effect of Sowing Date on Grain Yield of Soybeans at Wad Medani and Abu Naama

Abu Naama (1977-78)		Wad Medani (1978-79)	
Sowing date	Grain yield*	Sowing date	Grain yield**
	kilograms per hectare		kilograms per hectare
June 15	1,326	May 8	913
June 30	762	May 22	1,113
July 15	462	June 5	1,172
July 30	362	June 19	681
August 15	276	July 3	705
		July 17	486
		July 31	894
		August 14	678

* Average of two varieties (Semmes and Davis) and four plant spacings (5, 10, 15, and 30 cm).
**Average of two varieties (Semmes and Williams).

Table 4a. The Effect of Row Spacing on Grain Yield of Williams Soybeans, Wad Medani, 1978

Row spacing (centimeters)	Grain yield (kilograms per hectare)
20	1,485
40	1,451
60	1,754
80	1,284
S.E.	$\pm$ 88

*Table 4b. The Effect of Plant Spacing on the Grain Yield of Soybeans, Abu Naama, 1977-78**

Plant spacing (centimeters)	Grain yield (kilograms per hectare)
5	864
10	676
15	569
30	446

*Average of two varieties (Semmes and Davis) and five sowing dates.

Table 1. Yield of Selected Soybean Varieties at Wad Medani, 1973-74 to 1976-77*

Variety	Maturity group	1973-74	1974-75	1975-76	1976-77	Mean
			kilograms per hectare			
Williams	III	1,660	1,098	2,276	1,148	1,546
Semmes	VII	1,552	1,252	2,288	1,140	1,558
Davis	VI	1,381	619	1,148	1,031	1,045
Imp. Pelican	VIII	1,307	752	1,495	862	1,104
Coker-Hampton	VIII	1,248	1,317	1,529	900	1,249
Calland	III	1,181	1,033	1,210	786	1,053
Hardee	VIII	1,164	1,117	2,374	998	1,413
Clark 63	IV	810	833	1,138	1,031	953
Mean		1,288	1,003	1,682	987	1,240

*Out of 16 varieties included in the INTSOY program.

Table 2. Grain Yield of 1978 INTSOY ISVEX Trials at Wad Medani and Abu Naama

Wad Medani (Lat. 14°24')		Abu Naama (Lat. 12°44')	
Variety	Grain yield	Variety	Grain yield
	kilograms per hectare		kilograms per hectare
Hardee LS	2,714	UFV-1	1,093
Jupiter	2,622	Caribe	1,027
UFV-1	2,515	Cobb	1,010
Caribe	2,439	Tunia	904
Cobb	2,179	Gasoy 17	814
Williams	2,101	Williams	781
Rillito	1,899	Ransom	773
IAC-2	1,894	Rillito	770
Ransom	1,890	Hardee LS	766
Bossier	1,861	Jupiter	743
Orba	1,590	Orba	727
Imp. Pelican	1,550	Bossier	689
Tunia	1,509	IAC-2	493
SJ-2	1,231	Imp. Pelican	487
CH-3	1,200	SJ-2	483
Kahala	1,123	CH-3	356
S.E.	± 201	S.E.	± 142

Table 4c. The Effect of the Seed Rate on the Grain Yield of Williams Soybeans, Wad Medani, 1978

Seed rate (kilograms per hectare)	Grain yield (kilograms per hectare)
23.8	244
47.6	361
71.4	478
95.2	389
119.0	517
142.8	528
166.6	517
190.4	511
S.E.	± 44

Table 5a. The Effect of Inoculant and Nitrogen Applications on Soybean Yield, Abu Naama

Levels of nitrogen (kilograms per hectare)	Inoculation	Grain yield (kilograms per hectare)		
		1977-78	1978-79	Mean
None	Not inoculated	245	790	518
43	Not inoculated	367	1,136	752
86	Not inoculated	452	1,167	310
None	Inoculated	417	1,148	783
43	Inoculated	488	1,264	876
86	Inoculated	571	1,549	1,060

Table 5b. The Effect of Rate and Form of Inoculum (NITRAGIN) on Soybean Yields, Wad Medani, 1978-79

Granular form (soil applied)		Powder form (seed applied)	
Rate (kilograms per hectare)	Grain yield (kilograms per hectare)	Rate (grams per kilogram of seed)	Grain yield (kilograms per hectare)
0	543	0	543
2.78	896	2	843
5.56	1,193	4	1,119
8.34	1,154	6	1,102
11.12	1,248	8	850
Control[a]	1,439	Control	1,439
S.E.	± 95.6	S.E.	± 90.6

[a]Control equals no inoculation plus 129 kilograms of nitrogen per hectare.

Irrigated Soybean Production in Turkey

N. IZGIN AND N. ONDER

TURKEY IS LOCATED BETWEEN 36°AND 42°N LATITUDE. Syria, Iraq, and the Mediterranean Sea border Turkey on the south; the Aegean Sea, Greece, and Bulgaria on the west; the Black Sea on the north; and Russia and Iran on the east. The country is quite mountainous with a typically Mediterranean rainfall pattern where rain falls between October and May while the period from June to September is very dry. The coastal areas are free of frost but have cool winters and hot summers. Annual rainfall in the coastal areas ranges from 500 millimeters in the south to over 1,000 millimeters in the north. The rest of the country generally receives less than 400 millimeters per year.

Turkey's agriculture plays a dominant role in the nation's life and involves 65 to 70 percent of the population. The population increases approximately 3 percent per year. This rapid population increase means that the available resources are used. Therefore, an increase in agricultural production, parallel to that of the population, is necessary.

The country has a total area of 78.1 million hectares. Approximately 35 percent is cultivated, 26 percent is grass and pasture, and the remaining 39 percent is forest or unproductive land.

The area under cereal production (wheat, barley, maize, rice, and so forth) is the largest part of the cultivated land. Industrial crops (cotton, sugar beets, tobacco, and so forth), oilseed crops (such as sunflower, poppy, soybean, safflower, cotton, sesame, and rape), and food legumes (for example, chickpeas and lentils) follow the cereal production area in importance.

In recent years, Turkey has had a shortage in vegetable oil production of about 100,000 metric tons annually. Even though sunflowers are the most important oil crop in area and production, soybeans are one of the promising oil crops that may help to meet the domestic requirements.

Soybeans are used mainly as an oil crop and as animal feed. Since 1940, soybeans have been grown under rain-fed conditions in a limited area along the east side of the Black Sea coast. However, there are currently plans to introduce soybeans as a second crop following wheat in the southern coastal areas where irrigation facilities are available.

PRODUCTION TECHNOLOGY

Nationally, approximately 8,000 tons of soybeans are produced each year on 6,000 hectares of land. The average yield is approximately 1.3 tons per hectare (Table 1).

The soybean production area has decreased since 1969-70 with no increase in average annual yields because of the relatively low demand in domestic markets for the crop. Soybeans do not compete economically with other crops.

In order to reverse this situation and to accelerate production, the Ministry of Agriculture and CARE have emphasized the development of soybean production in the southern coastal areas. Through these efforts, 500 hectares of irrigated soybeans were planted by contracted farmers as a second crop in 1978 and 2,000 hectares were planted in 1979. Production in 1980 was expected to be 3,000 hectares. In 1978, the yield level was approximately 2 tons per hectare in this region. Amsoy 31 seed was provided by CARE for this program.

Soybeans are mainly grown as an intercrop with maize on the west side of the Black Sea coast. Cultural practices are poor. Soil preparation starts in the spring. The disc harrow is the only tillage equipment used. Planting is done by hand in May at the rate of 60 to 70 kilograms per hectare. Clark and Lincoln are the commercial varieties grown. Even though the yield potential of Clark is about 3.5 metric tons per hectare in this region, farmers get only 1.3 metric tons per hectare because of poor cultural practices. September is harvesttime in this region.

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Table 1. Hectares, Yield, and Production of Soybeans in Turkey

Year	Hectares	Yield (kg./ha)	Production (MT)
1969	8,160	1.348	11,000
1970	11,000	1.091	12,000
1971	7,000	1.571	11,000
1972	6,000	2.133	12,800
1973	5,070	1.460	7,400
1974	3,500	2.429	8,500
1975	6,200	1.089	6,750
1976	6,470	1.300	8,470
1977	6,000	1.300	8,000
1978	6,000	1.300	8,000

In the South, soybeans are a new crop and farmers are now learning good cultural practices. Soil preparation after the wheat harvest must be done quickly to complete planting between June 15 and June 20. The moldboard plow and disc harrow are the tillage equipment used and a cotton drill is used for planting with 50 to 80 centimeter row spacings. The recommended seeding rate is 40 to 50 kilograms per hectare. A fertilizer application of 60 to 80 kilograms of P_2O_5 per hectare and 40 to 60 kilograms of nitrogen per hectare is mixed with the soil before planting. Harvest starts during the second half of September. Wheat combines are used for harvesting. Amsoy 71 is the only commercial variety grown because of its early maturity (95 days) and resistance to white flies, which are the most harmful insects in the region.

No dependable research data are available on irrigation methods, water requirements, and frequency of application for maximizing soybean yields in the southern region. The first irrigation starts just after planting for proper germination and stand. Two or three additional irrigations are applied during the vegetative period. Local *Rhizobium* inoculum is available in Turkey. Effective *Rhizobium japonicum* strains have been isolated and increased by the Soil and Fertilizer Research Institute in Ankara. Out of 59 local and 31 imported strains, 8 strains have been found to be effective in Turkey through greenhouse and field experiments. The Institute distributes about 1,000 kilograms of inoculum annually. Application is accomplished by mixing 100 grams of the culture with 6 to 7 kilograms of seed at planting.

The agricultural research institutes and state farms are responsible for seed production in Turkey. The state farms receive basic seed from the research institutes. This basic seed is then used to produce certified seed on the state farm or by farmers under contract. Farmers then obtain their seed supply from the state farms.

For soybeans, this seed production chain is not yet established. At present, the Ministry of Agriculture is trying to start an effective seed-production program for the Amsoy 71 and Clark cultivars.

ORGANIZATION

A national research program called the Second Crop Research Project was initiated in 1978 under the Ministry of Agriculture. Three research institutes along the south coast are involved in this project. The main objectives are to develop maize, sorghum, sunflower, rice, and soybean cultivars as a second crop after wheat and to set up a package of cultural practices for the region.

The three institutes that are responsible for carrying out the soybean development program have adequate field and laboratory facilities. However, a lack of manpower specifically trained in soybean research is a major problem. Two soybean scientists with M.Sc. degrees and a project leader with a Ph.D will be necessary for each institute in the future.

Constraints to Effective Irrigated Soybean Production

Crop Production Constraints to Effective Irrigated Soybean Production[1]

CRITICAL CONSTRAINTS

Short Term

NATIONAL INTERVENTION

Develop country programs to screen, select, and maintain locally adapted varieties from segregated populations.

Improve seed production technology so that genetically pure seed with high germination can be provided to the farmer.

Develop management techniques to promote higher germination, more rapid emergence, and faster early plant growth under adequate irrigation.

NATIONAL AND INTERNATIONAL INTERVENTION

Develop improved soil and crop management practices for increased emergence and higher plant population under conditions of high temperatures, low humidity, and low soil moisture.

Obtain information on the interaction between nitrogen fixation by *Rhizobium* and plant use of other major nutrients.

Train research and extension officers in crop management and irrigation management techniques for irrigated soybean production.

Develop an improved communications system including publications for the international exchange of research information.

INTERNATIONAL INTERVENTION

Need a broad germplasm base to develop segregated soybean plant populations for the special conditions found in arid and semiarid regions, such as: high temperatures and low humidity; tolerance to saline, alkaline, and high pH soils and water; inadequate germination because of hot, frequently dry soils; and a tolerance to high and fluctuating water tables.

Develop short-season or early maturing varieties suitable for intense crop rotations and for double cropping after crops such as wheat and cotton.

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[1]*During the conference each participant was asked to serve on one of four working committees to identify constraints to effective irrigated soybean production. The committees were asked to designate constraints in crop production, plant protection, irrigation water management, and problems of policy. The committee members accepted their assignments with enthusiasm and discussed the issues vigorously. The committees were asked to submit a list of constraints and recommendations for action to remove them. These reports were presented to the conference.*

Medium Term

NATIONAL INTERVENTION

Improve management practices for time of planting, rate of seeding, and depth of planting.

Develop inoculant production within countries.

Obtain information on the optimum economic level for foliar fertilizers.

NATIONAL AND INTERNATIONAL INTERVENTION

Improve harvesting techniques and machinery for small farms.

Improve granular carriers for *Rhizobium*.

Obtain information on types of rhizobia bacteria that will fix nitrogen even when nitrogen fertilizer is applied.

Improve management practices for producing soybeans under a restricted irrigation water supply.

Develop systems for minimum or no-tillage production of irrigated soybeans.

INTERNATIONAL INTERVENTION

Develop threshing machines for small farms.

Improve *Rhizobium* strains and maintain stocks of improved cultures.

Obtain information on the residual effect of applied pesticides on the soybean crop.

IMPORTANT CONSTRAINTS

Short Term

NATIONAL INTERVENTION

Develop a system for identifying the most important problems and constraints and for initiating and carrying through research on the critical soil, crop, and irrigation management problems of irrigated soybean production.

Improve cropping rotations with soybeans or identify the optimal place for soybeans within present rotations.

Improve management practices for the production of soybeans under an adequate irrigation water supply.

Improve the system to communicate research results and problems between research and extension officers.

Improve drainage management of irrigated soils.

Improve systems for introducing improved varieties and irrigation management techniques to farmers.

Improve seed-production management practices to reduce the amount of green and shriveled seed produced in irrigated areas under high temperatures.

Develop varieties tolerant of short periods of low moisture supply because of restricted irrigation water or the low water-holding capacity of sandy soils.

Develop soybean varieties suitable for intercropping with other row crops.

NATIONAL AND INTERNATIONAL INTERVENTION

Improve seedbed preparation techniques in order to improve germination, emergence, and early plant growth.

Improve management techniques to reduce the amount of time needed for soil preparation and for planting in intensified cropping systems, as, for example, soybeans after wheat or cotton.

Improve management techniques to reduce flower and pod abortion from high temperatures.

Identify strains of *Rhizobium* that are tolerant to periodic soil stresses from low moisture, high temperatures, and salinity.

Improve methods of establishing and maintaining *Rhizobium* populations in the soil, especially under the stresses of high temperatures and low moisture.

Develop systems to increase the effectiveness of applied inoculants through improved carriers, better methods of application, superior strains of rhizobia, and optimum populations of bacteria.

Medium Term

NATIONAL AND INTERNATIONAL INTERVENTION

Improve soil and water practices to avoid infiltration and drainage problems in heavy clay and sodic soils.

Obtain knowledge of the economic production system of soybeans under irrigation both where there are restricted and nonrestricted resources of credit, labor, inputs, and so forth.

INFORMATION NEEDED TO REMOVE CONSTRAINTS

Short Term

NATIONAL INTERVENTION

Conduct market surveys to determine the preferences of consumers for soybeans of different sizes.

INTERNATIONAL INTERVENTION

Develop varieties with smaller seed.

Medium Term

NATIONAL AND INTERNATIONAL INTERVENTION

Develop varieties and crop management practices suitable for production using supplemental irrigation where there is an inadequate amount of rainfall.

Develop and introduce improved techniques and methods for leveling land to be irrigated and maintaining land in a level condition over several cropping seasons.

Evaluate the economic relationship between the application of nitrogen, phosphorus, potassium, and micronutrient fertilizers with various levels of irrigation.

Develop varieties suitable for specialized production such as small farmer, mechanized, and relay cropping systems.

Develop high yielding soybean varieties capable of nodulating and fixing nitrogen for high-altitude irrigated production areas.

Plant Protection Constraints to Effective Irrigated Soybean Production

SHORT TERM

National Intervention

Develop methods for controlling weeds, either by cultivation or by chemical herbicides.

AUSTRALIA

Johnson grass

Barnyard grass—*Echinochloa* sp.

Sesbania sp.

Abelmaschus sp.

Phylanthus sp.

ETHIOPIA

Galinsoga sp.

Xanthium sp.

Amaranthus sp.

Commelina sp.

MEXICO

Cyperus sp.

Physalis sp.

Leptochloa sp.

(This listing of weeds was made according to countries and geographical areas in general. Any single insect, disease, or weed problem could become the most important constraint in a particular country.)

Lack of knowledge about how to control insects and mites.

AUSTRALIA

Stem borer--*Zygrita diva*
Sucking bugs--*Nezara* sp.
Piezodorus sp.
Riptortus sp.

EGYPT

Cotton leaf worm--*Spodoptera* sp.
Spider mites--*Tetranychus* sp.
Velvet band caterpillar--*Anticarsia* sp.
Cotton boll worm--*Heliothis* sp.

SUDAN

Cotton leaf worm--*Spodoptera* sp.
Cotton boll worm--*Heliothis* sp.
Blister beetle--*Epicauta* sp.

BANGLADESH

Leaf roller
Hairy caterpillar
Aphids
Meal moth

MEXICO

Salt marsh caterpillar
Caliothrips sp.
Crickets

UNITED STATES

Spider mites--*Tetranychus* sp.

(This listing of insects and mites was made according to countries and geographical areas in general. Any single insect, disease, or weed problem could become the most important constraint in a particular country.)

Develop knowledge about how to control diseases and viruses.

AUSTRALIA

Seedling diseases

ETHIOPIA

Bacterial blight--*Pseudomonas glycinea*

SUDAN

Bacterial pustule--*Xanthemonas campestris*

BANGLADESH

Anthracnose--*Colletotrichum* sp.
Bacterial pustule--*Xanthomonas campestris*, *Xanthomonal phaseoli* var. *sojen*
Root rots
Yellow mosaic

SRI LANKA

Yellow mosaic

(This listing of diseases and viruses was made according to countries and geographical areas in general. Any single insect, disease, or weed problem could become the most important constraint in a particular country.)

Develop information on controlling vertebrates (rodents and birds) attacking soybeans in the field.

Develop information on controlling rodents attacking soybean grain in storage.

National and International Intervention

Improve cultural methods for controlling weeds in irrigated soybeans.

Develop knowledge of all soybean germplasm screened for insect resistance.

International Intervention

Obtain information on the proper timing of applications of herbicides for weed control.

Develop segregated soybean populations resistant to leaf-feeding insects.

Develop segregated soybean populations resistant to insects.

Develop segregated soybean populations resistant to viruses.

MEDIUM TERM

National and International Intervention

Survey producers to determine the economic threshold of losses from all pests of soybeans including insects, diseases, weeds, and vertebrates.

International Intervention

Identify alternatives to chemical insecticides for controlling major insect pests of irrigated soybeans.

Obtain knowledge of the physiology of soybean plant resistance to insect attack.

Irrigation Water Management Constraints to Effective Soybean Production

SHORT TERM

National Intervention

Need identified equipment for land preparation, planting, harvesting, and irrigating to meet critical time requirements of high intensity cropping.

Obtain knowledge about level basin water management.

International Intervention

Determine the time of day for the most effective application of irrigation water including peak water-demand periods, thermal stress, and wilting point.

MEDIUM TERM

National Intervention

Proper land levelling and grading for uniform water distribution.

Land levelling for soybeans grown in rotation with rice.

Improve scheduling of irrigation to maximize total farm production and production per unit of water.

Improper bedding and spacing between and within rows reduces plant stands, water-use efficiency, and yield.

Develop crop rotations and multiple cropping systems to maximize production, water-use efficiency, and economic return.

National and International Intervention

Learn about the effect of depth of water table on soybean growth and yield.

Learn about drainage requirements and the relationship of drainage to the aeration requirements of soybean plants.

Improve methods for drainage in relation to the control and prevention of salinity.

Learn about the effect of surface ponding of water on soybean growth yield.

LONG TERM

National Intervention

Obtain quantitative hydrology (groundwater, surface water, and precipitation) information in terms of quantity and quality of water available on a local and national basis.

Develop standardized minimum data including climate, soil, plant growth stages, and agronomic factors in order to generate crop yield and water use models.

Obtain information about the available water in the root zone in order to develop crop yield and water use models.

Develop equipment to meet critical time requirements of high-intensity cropping systems for land preparation, planting, harvesting, and irrigation.

Train research and extension officers in irrigation water management.

National and International Intervention

Improve design and construction criteria for water-distribution systems.

Improve systems for the operation and management of water distribution.

Integrate and coordinate systems of water distribution and systems for on-farm water management.

International Intervention

Develop quantitative hydrologic (groundwater, surface water, and precipitation) information on a regional basis in terms of the quantity and quality of available water.

Improve the definition of the relationship between soybeans and salinity including plant physiological mechanisms, quantitative prediction of the effects of salinity, and the application of this information to crop management and plant breeding for tolerance to salinity.

Policy Constraints in Effective Irrigated Soybean Production

SHORT TERM

National Intervention

Improve operating procedures for irrigation water distribution systems, including closer coordination between water distribution and on-farm water management.

Initiate an adequate soybean crop purchasing system and set a guaranteed price for soybeans high enough for the farmer to receive a favorable net profit in order to encourage an increase in production.

MEDIUM TERM

National Intervention

Formulate an irrigation water-distribution policy that leads to more efficient water use and higher crop production per unit of applied water.

Improve input (credit, fertilizer, machinery, pesticides, seed, and so forth) supply system so that farmers have adequate incentives to initiate and increase soybean production.

LONG TERM

National Intervention

Improve water distribution and drainage plans to more uniformly allocate irrigation water, to prevent waterlogging and salinity, and to ensure adequate drainage.

Conference Summary

Irrigated Soybean Production in Arid and Semi-Arid Regions: Conference Summary

W.N. THOMPSON

A BETTER LABEL FOR MY COMMENTS would be "Some Comments Near the End of the Conference." To briefly summarize the presentations and deliberations of the conference would be impossible; furthermore, it would be redundant and I would seem quite arrogant to pretend that I could summarize a week's deliberations within a few minutes.

The keynote speaker properly set the theme of the conference within a broad framework, stressing the significance of factors in addition to those directly affecting soybean production. He pointed up the importance of three sets of factors—marketing, biological aspects, and development—for the successful introduction and establishment of a new crop such as soybeans. The papers, discussions, working sessions, and information about individual country experiences confirmed the importance of considering irrigated soybean production as a part of the broader picture.

Although each set of factors is important and there are many interrelationships, Dr. Knowles rightfully placed market factors first in his outline. Neither governments nor farmers can be interested for very long in producing a product without the incentive of a good market and adequate prices realized through participation in such a market.

The importance of having a suitable market as well as the functions of the marketing process being carried out effectively have been illustrated in the country reports as well as in several of the papers. Dr. Knowles pointed out that consideration must be given to the marketing of both the oil and the protein component of soybeans. The matter is not a simple one because soybeans can be used in many ways—livestock feed, cooking oil, processed vegetable fats, processed protein foods, soybean milk, industrial uses, and so on. Then, there is the question of use within the country of production or of export to deficit areas.

Soybeans have become the dominant crop in world commerce as the supplier of vegetable oil and of protein. International marketing is extremently competitive. In general, a country that is initiating soybean production will want to give first priority to fulfilling its domestic needs for vegetable oil and protein for use as human food and animal feed. Other crops will serve as sources of these food components, too, so achieving a balanced supply of the various components from different sources must be considered.

The developmental factors, that is, organizational and institutional considerations, are usually the most serious constraints on the expanded production of food and fiber generally, on the production and marketing of grain legumes and oilseeds, and on research and extension efforts designed to undergird production and marketing efforts. Let me give you some illustrations. A committment to agricultural development generally as well as to the introduction or significant expansion of a new crop is imperative for expanded production. Research continuity must be provided, both in terms of organizations and individual scientists. The research must be directly relevant to the problems of the farmer or, in the case of marketing, to those involved in that process. Extension education programs are necessary in order to provide the required link between the farmer and those who carry out the marketing functions. Personnel for all aspects of the agricultural development process need to be educated and trained. Other requirements include the availability of inputs and incentives for farmers to produce. These are only examples of the factors that must be attended to if success is to be achieved with an individual crop or in a general agricultural development.

The primary focus of this conference has been on the biological and closely associated production factors. A number of countries have taken steps to relieve those constraints to the expanded production of soybeans. The basic factors are the same for rain-fed or for irrigated production. However, production under irrigation conditions requires

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special attention. Information presented here has shown clearly that soybeans can be grown under many of the physical and biological conditions of arid and semiarid regions using technology we already have. Soybeans can be grown not only under experimental conditions, but also commercially. The experiences of a number of countries bear this out. Examples include Egypt, Mexico, Colombia, Sri Lanka, and the United States (particularly in such states as California and Kansas). The conference has shown that a large body of knowledge is available concerning the production of soybeans under irrigated conditions. One of the speakers made the point that there is "a lot of irrigation technology on the shelf." Some of this technology was developed specifically for soybeans; but there is a much larger body of knowledge and technology available for other crops, some of which could be transferred rather directly to the soybean crop.

The Organizing Committee and Program Advisory Committee are to be commended for developing a program with an effective combination of invited papers, country reports, contributed papers, and working committee sessions to identify constraints and problems in soybean production under irrigation. The invited papers contained both depth and breadth in research results on the production of soybeans under arid and semiarid conditions. The country reports provided an excellent review of experiences with soybean production generally, with a special emphasis on experiences relating to production under irrigation. The country-report format provided by the Organizing Committee was useful in encouraging the authors to focus attention on common points, thereby making possible comparisons across country lines. The question and discussion periods generated interchange among participants. Of the many conferences and workshops in which I have participated, this one has been the best in terms of a serious, yet informal and friendly, exchange of ideas.

The working committee sessions supplemented the invited papers in focusing on research needs and priorities. The field trip provided the opportunity to visit a farm as well as Menoufeia University and its soybean experiments. These experiments clearly show the tremendous potential for soybean production. At the same time, the farm visit pointed up the realities of farm production and family living under the harsh environment of arid agriculture.

This conference has been a timely one. The amount of rain-fed land for soybean production properly located with respect to markets is limited. In the future, there will be an increasing interest in producing soybeans under irrigated conditions. The limitations of water and energy and of other costs required to get the water to the crop when needed require greater attention to making the production process efficient and profitable for the farmer. This conference has made an important contribution to that by assembling the information now available as well as by identifying research and educational priorities for the future.

A successful soybean industry requires a suitable continuity of research efforts. This is demonstrated by experience in the United States. Intensive research has been conducted there for more than 40 years. The research needs continue. In 1979, more U.S. land is in soybeans than in any other crop.

In general, crop expansion demands greater adaptive research efforts as well as more intensity of effort in getting research results to the farmer and marketer. One of the speakers emphasized the need for research planning and design on an international scale. The logic of this point is self-evident. Cooperation in research and improved communication are needed. There are tremendous potentials in drawing on the research results of others and learning from both research information and farm experience under similar and different environments. I am confident that this conference has made a contribution to that need.

A major item in the success of the conference has been the hospitality of our Egyptian hosts, which has permeated the atmosphere at all times. The friendliness and cordiality added to the informality and interaction among participants. The professional and personal friendships made here are certain to lead to enduring exchanges of ideas among those interested in furthering the production, marketing, and use of soybeans.

In closing, I express INTSOY's appreciation to the many who have contributed to the success of this conference. Special mention should be made of the joint sponsors, the Egyptian Ministry of Agriculture and Menoufeia University, as well as the support of the Food and Agriculture Organization of the United Nations and the U.S. Agency for International Development. Finally, thanks are due to the members of the Organizing Committee for planning and carrying out the many details required for such a conference so effectively.